# DOCUMENT RESUME

ED 246 216 CE 039 201

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|---|---|
| TITLE | Electronic Principles I, 7-5. Military Curriculum Materials for Vocational and Technical Education. |
| INSTITUTION | Air Force Training Command, Keesler AFB, Miss.; Ohio State Univ., Columbus. National Center for Research in Vocational Education. |
| SPONS AGENCY | Department of Education, Washington, DC. |
| PUB DATE | 75 |
| NOTE | 788p.; For related documents, see CE 039 202-210. |
| PUB TYPE | Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052) |
| EDRS PRICE | MF05/PC32 Plus Postage. |
| DESCRIPTORS | Behavioral Objectives; Course Content; Course Descriptions; *Electric Circuits; Electronic Equipment; *Electronics; First Aid; Individualized Instruction; Learning Activities; Learning Modules; *Mathematics; Pacing; Postsecondary Education; Programed Instructional Materials; Safety; Secondary Education; *Technical Education |
| IDENTIFIERS | Military Curriculum Project |

ABSTRACT

This first of 10 blocks of student and teacher materials for a secondary/postsecondary level course in electronic principles comprises one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. This block on DC circuits contains nine modules covering 53 hours of instruction on safety and first aid (2 hours); electronic mathematics (6); direct current and voltage (3); resistance, resistors, and schematic symbols (5); multimeter uses (6); series resistive circuits (5); parallel resistive circuits (5); series-parallel resistive circuits (13); and troubleshooting DC resistive circuits (8). Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include two student texts; guidance packages for modules 3 through 10 containing objectives and review exercises; four programmed texts; and two handouts. A digest of the modules in the block is provided for students who need only to review the material. Designed for self- or group-paced instruction, the material can be adapted for individualized instruction. Additional print and audiovisual materials are recommended but not provided. (YLB)

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## MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

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- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

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**Military Curriculum Materials**
**WRITE OR CALL**
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

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# Military Curriculum Materials for Vocational and Technical Education

## Information and Field Services Division

**The National Center for Research in Vocational Education**

# Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

**Project Staff:**

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

# What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

# How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

## CURRICULUM COORDINATION CENTERS

**EAST CENTRAL**
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

**MIDWEST**
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

**NORTHEAST**
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

**NORTHWEST**
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

**SOUTHEAST**
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

**WESTERN**
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

# ELECTRONICS PRINCIPLES 1

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## ELECTRONICS PRINCIPLES 1

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# ELECTRONIC PRINCIPLES I

Classroom Course

7-5 1

**Developed by:**
United States Air Force

**Development and Review Dates:**
July 1974 through November 1975

**D.O.T. No.:**
003.081

**Occupational Area:**
Electronics

**Target Audiences:**
Grades 11-adult

**Print Pages:**
780

**Cost:**
$15.75

**Availability:**
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

| Contents: | Type of Materials: Lesson Plans: | Programmed Text: | Student Workbook: | Handouts: | Text Materials: | Audio-Visuals: | Instructional Design: Performance Objectives: | Tests: | Review Exercises: | Additional Materials Required: | Type of Instruction: Group Instruction: | Individualized: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | No. of pages | | | | | | | | | |
| Block I – *DC Circuits* | | | | | | | | | | | | |
| Module 2 – Safety and First Aid | ● | | 17 | | ● | ★ | ● | ★ | ● | | ● | ● |
| Module 3 – Electronic Mathematics | ● | ● | 111 | | ● | ★ | ● | ★ | ● | | ● | ● |
| Module 4 – Direct Current and Voltage | ● | | 24 | ● | ● | ★ | ● | ★ | ● | | ● | ● |
| Module 5 – Resistance, Resistors, and Schematic Diagrams | ● | | 24 | | ● | ★ | ● | ★ | ● | ★ | ● | ● |
| Module 6 – Multimeter Uses | ● | | 8 | ● | ● | ★ | ● | ★ | ● | ★ | ● | ● |
| Module 7 – Series Resistive Circuits | ● | ● | 11 | | ● | ★ | ● | ★ | ● | | ● | ● |
| Module 8 – Parallel Resistive Circuits | ● | ● | 7 | | ● | ★ | ● | ★ | ● | | ● | ● |
| Module 9 – Series Parallel Resistive Circuits | ● | ● | 16 | | ● | ★ | ● | ★ | ● | ★ | ● | ● |
| Module 10 – Troubleshooting DC Resistive Circuits | ● | ● | 10 | | ● | ★ | ● | ★ | ● | ★ | ● | ● |

★ Materials are recommended but not provided.

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**Course Description:**

This block is the first of ten blocks providing training in electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting basic circuits. Block I—*DC Circuits* contains 9 modules covering 53 hours of instruction on safety, mathematics, voltage, resistance, test equipment, and circuit analysis. Module 1—Orientation was deleted because it contains military specific information and tasks. The selected modules and respective hours follow:

Module 2 — **Safety and First Aid** (2 hours)
Module 3 — **Electronic Mathematics** (6 hours)
Module 4 — **Direct Current and Voltage** (3 hours)
Module 5 — **Resistance, Resistors, and Schematic Symbols** (5 hours)
Module 6 — **Multimeter Uses** (6 hours)
Module 7 — **Series Resistive Circuits** (5 hours)
Module 8 — **Parallel Resistive Circuits** (5 hours)
Module 9 — **Series-Parallel Resistive Circuits** (13 hours)
Module 10 — **Troubleshooting DC Resistive Circuits** (8 hours)

This block contains both teacher and student materials. Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include two student texts, *Electronics Handbook* and *DC Principles*, which are used for all the modules; guidance packages for modules three through ten containing objectives and review exercises; four programmed texts on electronic mathematics, series resistive circuits, parallel resistive circuits and series-parallel resistive circuits; and two handouts on DC, AC, and RCL circuits and test equipment operating instructions. In addition a digest of the first ten modules is provided for students who have a background in these topics and only need to review the major points of instruction.

This material is designed for self- or group-paced instruction. Most of the materials can be adapted for individualized instruction. Some additional military manuals and commercially produced texts are recommended as references but these are not provided. Audiovisuals suggested for use with the entire course include 143 videotapes. **Electronic Principles I** should be used with the remaining 9 blocks to form a complete course in electronic principles.

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# PLAN OF INSTRUCTION
## (Technical Training)

ELECTRONIC PRINCIPLES

(Modular Self-Paced)

KEESLER TECHNICAL TRAINING CENTER

6 November 1975 - Effective 6 January 1976 with Class 760106

Volume 1

7-5

ATC Keesler 4-2148

DEPARTMENT OF THE AIR FORCE
USAF Sch of Applied Aerosp Sci (ATC)
Keesler Air Force Base, Mississippi 39534

PLAN OF INSTRUCTION 3AQR30020-1
6 November 1975

## FOREWORD

1. PURPOSE: This publication is the plan of instruction (POI) when the pages shown on page A are bound into a single document. The POI prescribes the qualitative requirements for Course Number 3AQR30020-1, Electronic Principles (Modular Self-Paced) in terms of criterion objectives and teaching steps presented by modules of instruction and shows duration, correlation with the training standard, and support materials and guidance. When separated into modules of instruction, it becomes Part I of the lesson plan. This POI was developed under the provisions of ATCR 50-5, Instructional System Development, and ATCR 52-7, Plans of Instruction and Lesson Plans.

2. COURSE DESIGN/DESCRIPTION. The instructional design for this course is Modular Scheduling and Self-Pacing; however, this POI can also be used for Group Pacing. The course trains both non-prior service airmen personnel and selected re-enlistees for subsequent entry into the equipment oriented phase of basic courses supporting 303XX, 304XX, 307XX, 309XX and 328XX AFSCs. Technical Training includes electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting of basic circuits. Students assigned to any one course will receive training only in those modules needed to complement the training program in the equipment phase. Related training includes traffic safety, commander's calls/briefings and end of course appointments.

3. TRAINING EQUIPMENT. The number shown in parentheses after equipment listed as Training Equipment under SUPPORT MATERIALS AND GUIDANCE is the planned number of students assigned to each equipment unit.

4. REFERENCES. This plan of instruction is based on Course Training Standard KE52-3AQR30020-1, 27 June 1975 and Course Chart 3AQR30020-1, 27 June 1975.

FOR THE COMMANDER

W. H. HORNE, Colonel, USAF
Commander
Tech Tng Gp Prov, 3395th

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OPR: Tech Tng Gp Prov, 3395th
DISTRIBUTION: Listed on Page A

# MODIFICATIONS

Module 1 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| I | DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 2. Safety and First Aid (Module 2) | 2<br>(2/0) |

a. From a group of statements, select those that describe safety precautions which should be observed when working on electrical equipment. CTS: 1a Meas: W

- (1) Accident causes
  - (a) Human error
  - (b) Material failure
- (2) Electrical hazards
  - (a) High voltage and current
  - (b) Fusing equipment

b. From a group of statements, select those which name the proper first aid measure to be used for the treatment of electrical shock. CTS: 1b Meas: W

- (1) Factors determining severity of electrical shock.
  - (a) Part of body involved.
  - (b) Amount of current.
  - (c) Length of contact.
- (2) Treatment of severe electrical shock.
  - (a) Turn circuit power off.
  - (b) Remove victim
  - (c) Artificial Respiration

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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ATC FORM APR 75 133 ATC Keesler 6-1029 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

c. From a list of fire extinguisher types, select the one used for electrical fires. CTS: 1a Meas: W

(1) Classes of fires

(a) Class "A" fire

(b) Class "B" fire

(c) Class "C" fire

(2) Types of fire extinguishers.

## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-2, Safety and First Aid
KEP-112, Safety Precautions and First Aid for Electronic Principles
ATC-PT-52-11
KEP-ST-1, DC Principles

Audio Visual Aids
TVK-30-101B, Safety

Training Methods
Discussion (2 hrs) and/or Programmed Self Instruction

Instructional Guidance
Issue KEP-GP-2, KEP-ST-112 and KEP-ST-1. Portions of this material have been covered at Lackland AFB during basic training. Encourage students to discuss what they have already learned.

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## PLAN OF INSTRUCTION/LESSON PLAN PART I

| | |
|---|---|
| NAME OF INSTRUCTOR | COURSE TITLE<br>Electronic Principles |
| BLOCK NUMBER<br>I | BLOCK TITLE<br>DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 3. Electronic Mathematics (Module 3) | 6<br>(6/0) |

a. Given five multiplication and five division problems, solve by using powers of ten. CTS: 3b Meas: W; PC

(1) Define

(a) base number.

(b) exponent.

(c) numerical coefficient.

(2) Convert numbers to powers of ten.

(3) Solve problems requiring use of powers of ten for

(a) multiplication.

(b) division.

(c) addition.

(d) subtraction.

b. Given five electronically related equations, solve at least four correctly for any unknown value. CTS: 3b Meas: W; PC

(1) Define "equation."

(2) Apply axioms in equation problems.

(3) Transpose terms in equations.

(4) Solve simple equations.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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## PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

### COURSE CONTENT

### SUPPORT MATERIALS AND GUIDANCE

**Student Instructional Materials**
KEP-GP-3, Electronic Mathematics
KEP-ST-1
KEP-107, DC, AC and RCL Circuits
KEP-HO-110, Electronics Handbook
KEP-PT-3, Electronic Mathematics

**Audio Visual Aids**
TVK 30-153, Powers of Ten
TVK 30-156, Simple Equations
TVK 30-103, Powers of Ten

**Training Methods**
Discussion (6 hrs) and/or Programmed Self Instruction

**Instructional Guidance**
Issue KEP-GP-3, KEP-107 and KEP-HO-110. Discuss powers of ten conversions and computations. Relate powers of ten to standard prefixes and explain how to solve electronic equations for an unknown value. After completion of GP-3, administer progress check and record results for each student.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| | |
|---|---|
| NAME OF INSTRUCTOR | COURSE TITLE<br>Electronic Principles |
| BLOCK NUMBER<br>I | BLOCK TITLE<br>DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 4. Direct Current and Voltage (Module 4) | 3<br>(3/0) |

a. From a group of statements, select the ones which describe a conductor and an insulator. CTS: 3a Meas: W

(1) Describe the structure of matter.

(a) Atomic structure

(b) Sub-atomic structure

(2) Define and give examples of elements, compounds, and mixtures.

(3) Define ionization.

(4) Explain the electrical characteristics of conductors, semi-conductors and insulators.

b. From a group of statements, select the one that describes the movement of free electrons within a conductor. CTS: 3a Meas: W

(1) Describe the atomic structure of conductors

(a) Valence electrons

(b) Free electrons

c. From a group of terms and symbols, select those which name the unit of measurement and symbol of electron flow. CTS: 3a Meas: W

(1) Relate the symbols for current and amperage.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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COURSE CONTENT

d. From a group of statements, select the one which describes the pressure that causes the movement of free electrons within a conductor. CTS: 3a Meas: W

(1) Requirements for current flow

(2) Define electromative force

e. From a group of terms and symbols, select those which name the unit of measurement and the symbol for Electromotive Force. CTS: 3a Meas: W

(1) Relate the symbols for volt and voltage (EMF).

f. From a group of statements, select five that describe common sources of electromotive force. CTS: 3a Meas: W

(1) List and give examples of the following sources of EMF.

(a) Mechanical

(b) Chemical

(c) Thermal

## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-4, Direct Current and Voltage
KEP-ST-1
KEP-107
KEP-110

Audio Visual Aids
TVK 30-101 C, Electrical Properties of Matter
TVK 30-101 D, Charged Bodies
TVK 30-101 E, Voltage
TVK 30-101 F, Current

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction

Instructional Guidance
Issue KEP-GP-4. Explain how atomic structure determines the conductivity of a material. Define and give symbols for all terms related to current and voltage.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
|  | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| I | DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 5. Resistance, Resistors, and Schematic Symbols (Module 5) | 4<br>(4/0) |

a. From a group of statements, select the one that describes the opposition to the movement of free electrons within conductor. CTS: 3a Meas: W

(1) Define Resistance.

b. From a group of terms and symbols, select those which name the unit of measurement and the symbol for resistance. CTS: 3a Meas: W

(1) Relate the symbols for resistance and ohm.

c. From a group of resistor symbols, select the symbol for a fixed, tapped, and variable resistor. CTS: 3a Meas: W

(1) Resistor symbols

d. Given five resistor pictorials, classify each as carbon, fixed wire, slide tap, rheostat, or potentiometer. CTS: 3a Meas: W

(1) Relate types of resistors to physical appearance.

e. From a group of schematic symbols, select the one that represents a battery; fuse; conductor; lamp; switch. CTS: 3a Meas: W

(1) Schematic symbols commonly used in electronics.

f. Using a resistor color code chart, determine the assigned value of five composition resistors. CTS: 3c Meas: PC

(1) End-to-center resistor color coding system.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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COURSE CONTENT

(2) Use laboratory exercise as practice in reading color codes.

g. Given four schematics showing two, three, or four batteries connected together, select the schematic connected for maximum output voltage.
CTS: 3b Meas: W

(1) Illustrate connections for batteries in

(a) series.

(b) parallel

(c) series-parallel.

(2) Compare the output voltage of each type connection.

6. Measurement and Critique (Part 1 of 2 Parts) 1

a. Measurement Test

b. Test Critique

## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-5, Resistance, Resistors and Schematic Symbols
KEP-ST-1
KEP-107
KEP-110

Audio Visual Aids
TVK 30-101 G, Resistance
TVK 30-101 H, Circuit Symbols & Components
TVK 30-101 V, Review of Safety and Electronic Mathematics

Training Equipment
DC Resistor Trainer 5531 (1)

Training Methods
Discussion (3.5 hrs) and/or Programmed Self Instruction
Performance (.5 hrs)

Multiple Instructor Requirements
Equipment (2)

Instructor Guidance
Issue KEP-GP-5. During performance of laboratory exercise, monitor students closely to insure proper use of equipment. No formal progress check is required. Discuss test procedures and direct student to test room.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| | |
|---|---|
| NAME OF INSTRUCTOR | COURSE TITLE<br>Electronic Principles |

| | |
|---|---|
| BLOCK NUMBER<br>I | BLOCK TITLE<br>DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 7. Multimeter Uses (Module 6) | 4<br>(4/0) |

a. From a group of statements concerning the multimeter, select the one which identifies the purpose of a function switch; range switch; ohms zero adjust. CTS: 2b Meas: W

(1) Using a mock-up, identify the switches and the ohms zero adjust.

(2) State the purpose of each switch and the ohms adjust.

b. Given a multimeter, identify the test leads; voltage scales; current scales; resistance scales; polarities. CTS: 2b Meas: PC

(1) Using a mock-up, identify each scale.

c. Using the multimeter and trainer, measure resistance, AC voltage and DC voltage with ± 10 percent accuracy. CTS: 2b, 1a Meas: PC

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-6, Multimeter Uses
KEP-ST-1
KEP-107
KEP-110
KEP-108, Test Equipment Operating Instructions

Audio Visual Aids
TVK 30-101 I, Volt Meter
TVK 30-101 J, Ammeter
TVK 30-101 K, Ohm Meter

Training Equipment
AC Inductor and Capacitor Training 5967 (1)
DC Resistor Trainer 5531 (1)
DC Power Supply 4649 (1)
Multimeter AN/PSM-6 (1)

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
Performance (1 hr)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance
Issue KEP-GP-6. Supervise performance of laboratory exercises. Administer progress check and record results for each student.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| | |
|---|---|
| NAME OF INSTRUCTOR | COURSE TITLE<br>Electronic Principles |
| BLOCK NUMBER<br>I | BLOCK TITLE<br>DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 8. Series Resistive Circuit (Module 7) | 5<br>(5/0) |

8. Series Resistive Circuit (Module 7)

a. Given four diagrams, select the one which satisfies the requirements for a DC circuit. CTS: 3a Meas: W

(1) Basic requirements for current flow

b. From a group of statements, select the one that describes Ohm's Law as related to current, voltage, and resistance. CTS: 3a Meas: W

(1) Define "Ohm's Law."

(2) Transposed forms of Ohm's Law.

c. Given a series circuit schematic diagram and formulas, solve for total resistance; total current; total power. CTS: 3b Meas: W

(1) Ohm's Law as applied to series circuits.

(2) Kirchhoff's Law as applied to series circuits.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

| SIGNATURE | DATE | SIGNATURE | DATE |
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| 3AQR30020-1 | 6 November 1975 | 13 |

ATC FORM APR 75 133 ATC Keesler 6-1029 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

## PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

### COURSE CONTENT

### SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-7, Series Resistive Circuits
KEP-ST-1
KEP-107
KEO-110
KEP-PT-7, Series Resistive Circuits
Audio Visual Aids
TVK-30-101 L, Series Circuits (Analysis)
TVK-30-101 M, Series Circuits (Power)

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction

Instructional Guidance
Issue KEP-GP-7. Give students ample practice in identifying formulas and solving problems.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| I | DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 9. Parallel Resistive Circuits (Module 8) | 5<br>(5/0) |

a. From a group of statements, select the ones that describe Kirchhoff's Law for current and for voltage. CTS: 3a Meas: W

(1) Kirchhoff's Laws for closed loops as applied to parallel circuits.

b. Given a parallel circuit schematic diagram and formulas, solve for total resistance; total current; total power. CTS: 3b Meas: W

(1) Relate formulas for total resistance.

(a) Reciprocal

(b) Product over the sum

(c) Special formula for equal sized resistors. Kirchhoff's Law for total current in parallel circuits. Total power in parallel circuits.

c. Given a bridge circuit schematic diagram, make necessary calculations to determine whether the circuit is balanced or unbalanced. CTS: 3b Meas: W

### SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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| 3AQR30020-1 | 6 November 1975 | 15 |

ATC FORM APR 75 133 ATC Keesler 6-1029 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-8, Parallel Resistive Circuits
KEP-ST-1
KEP-107
KEP-110
KEP-PT-8, Parallel Resistive Circuits
Audio Visual Aids
TVK-30-101 P, Parallel Circuits (Analysis)
TVK-30-101 R, Resistive Bridge Circuits
TVK-30-101 Q, Parallel Circuits (Power)

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction

Instructional Guidance
Issue KEP-GP-8. Check for students having trouble with using powers of ten in problem solving.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| | |
|---|---|
| NAME OF INSTRUCTOR | COURSE TITLE<br>Electronic Principles |

| | |
|---|---|
| BLOCK NUMBER<br>I | BLOCK TITLE<br>DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 10. Series-Parallel Resistive Circuits (Module 9) | 13<br>(9/4) |
| a. Given a series-parallel circuit schematic diagram and formulas, solve for total resistance; total current; total power; individual voltage drops. CTS: 3b Meas: W | (7) |
| (1) Ohm's Law as applied to series-parallel circuits | |
| (2) Kirchhoff's Laws as applied to series-parallel circuits | |
| b. Using a multimeter and a trainer with a loaded voltage divider, determine the polarity and measure the magnitude of a voltage with respect to the ground reference point with ± 10 percent accuracy. CTS: 3b, 2b, 1a Meas: PC | (1) |
| c. Using a multimeter and a trainer with a three-component series-parallel resistive circuit, measure, within ± 10 percent accuracy, the total resistance, and individual voltage drops. CTS: 2b, 3b Meas: PC | (1) |

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

| SIGNATURE | DATE | SIGNATURE | DATE |
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**PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)**

**COURSE CONTENT**

## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-9, Series-Parallel Resistive Circuits
KEP-ST-1
KEP-107
KEP-110
KEP-PT-9, Series-Parallel Resistive Circuits

Training Equipment
DC Resistor Trainer 5531 (1)
AN/PSM-6 (1)

Audio Visual Aids
TVK-30-101 O, Voltage Dividers
TVK-30-101 U, Loaded Voltage Dividers
TVK-30-101 S, Series-Parallel Resistive Circuits

Training Methods
Discussion (7 hrs) and/or Programmed Self Instruction
Performance (2 hrs)
CTT Assignment (4 hrs)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance
Issue KEP-GP-9. Supervise performance of laboratory exercises. Monitor students closely to insure proper safety precautions and correct use of laboratory equipment. Administer progress check and record results for each student. Assign objectives to be accomplished outside of classroom during CTT time.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| | |
|---|---|
| NAME OF INSTRUCTOR | COURSE TITLE<br>Electronic Principles |
| BLOCK NUMBER<br>I | BLOCK TITLE<br>DC Circuits |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 11. Troubleshooting DC Resistive Circuits (Module 10) | 8<br>(6/2) |
| a. Using a multimeter, formulas, schematic diagram, and a trainer having an open or shorted component in a series-parallel resistive circuit, locate the faulty component. CTS: 3c, 2b, 1a Meas: PC | |
| 12. Measurement and Critique (Part 2 of 2 Parts) | 1 |
| a. Measurement test | |
| b. Test Critique | |
| 13. Related Training (identified in course chart) | 10 |

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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**PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)**

**COURSE CONTENT**

## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-10, Troubleshooting DC Resistive Circuits
KEP-ST-1
KEP-107
KEP-110

Audio Visual Aids
TVK-30-101 N, Series Circuits (T/S)
TVK-30-101 T, Parallel Circuits (T/S)
TVK-30-101 V (2), Review: E, I, R and Symbols
TVK-30-101 V (3), Review: Volt-ohm Meter
TVK-30-101 V (4), Review: Series and Parallel Circuits
TVK-30-101 V (5), Review: Series and Parallel Circuits

Training Equipment
DC Resistor Trainer 5531 (1)
DC Power Supply 4649 (1)
Multimeter AN/PSM-6 (1)

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
Performance (2 hrs)
CTT Assignment (2 hrs)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance
Issue KEP-GP-10. Supervise performance of laboratory exercises.

Administer progress check and record results. Inform students that Part 2 of the measurement test covers modules 6 through 10. Assign objectives to be completed outside of classroom during CTT time.

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ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP ST/DIGEST I

Technical Training

# Electronic Principles (Modular Self-Paced)

## Block I

## DIGEST

1 April 1975

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 6-2460

DO NOT USE ON THE JOB

Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Student Text 3AQR3X020-X
KEP-ST/DIGEST I-III
1 April 1975

## DIGESTS

The digest is designed as a refresher for students with electronics experience and/or education who may not need to study any of the other resources in detail.

After reading a digest, if you feel that you can accomplish the objectives of the module, take the module self-check in the back of the Guidance Package. If you decide not to take the self-check, select another resource and begin study.

## CONTENTS

| MODULE | TITLE | PAGE |
|---|---|---|
| 2 | Safety and First Aid | 1 |
| 3 | Electronic Mathematics | 1 |
| 4 | Direct Current and Voltage | 3 |
| 5 | Resistance, Resistors, and Schematic Symbols | 4 |
| 6 | Multimeter Uses | 8 |
| 7 | Series Resistive Circuits | 9 |
| 8 | Parallel Resistive Circuits | 10 |
| 9 | Series-Parallel Resistive Circuits | 11 |
| 10 | Troubleshooting DC Resistive Circuits | 12 |
| 11 | AC Computation and Frequency Spectrum | 12 |
| 12 | Capacitors and Capacitive Reactance | 15 |
| 13 | Magnetism | 17 |
| 14 | Inductors and Inductive Reactance | 18 |
| 15 | Transformers | 20 |
| 16 | Relays | 21 |
| 17 | Microphones and Speakers | 21 |
| 18 | Meter Movements and Circuits | 22 |
| 19 | Motors and Generators | 24 |
| 20 | Oscilloscope Uses | 25 |
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| 23 | Troubleshooting Series and Parallel RCL Circuits | 30 |
| 24 | Series Resonance | 30 |
| 25 | Parallel Resonance | 32 |
| 26 | Transients | 33 |
| 27 | Filters | 35 |
| 28 | Coupling | 36 |

## MODULE 2

## SAFETY AND FIRST AID

### CAUSES OF ACCIDENTS

Accidents are expensive. The result of accidents is the loss, damage, or destruction of equipment, as well as injury and death to personnel. Accidents can be prevented by eliminating their causes. Some of the common causes of accidents are:

1. Carelessness
2. Horseplay
3. Lack of experience
4. Failure to follow instructions
5. Failure to observe proper safety precauions
6. Improper use of tools and equipment.

### PRECAUTIONS

The possibility of electrical shock is the greatest hazard associated with electronic equipment. Some of the precautions to always observe while working on electronic equipment are:

1. Remove jewelry
2. Keep one hand in your pocket
3. Have a safety observer
4. Avoid contact with energized components
5. Don't experiment.

### ELECTRICAL SHOCK TREATMENT

In the event of an accident and the body comes in contact with an energized component, the electric shock may be severe enough to interrupt normal body functions and cause respiratory system or heart failure. The proper first aid treatment for severe electric shock is the immediate restoration of the victim's heartbeat and breathing. The use of closed chest heart massage is recommended for the restoration of the heartbeat and mouth to mouth resuscitation is recommended for the restoration of breathing.

### ELECTRICAL FIRES

Electrical fires are a result of equipment failure or misuse. The use of a water type extinguisher on an electrical fire is not feasible because the water would place the operator in contact with the electrical components. A dry chemical such as carbon dioxide must be used to displace the oxygen near the fire to extinguish the blaze.

## MODULE 3

## ELECTRONIC MATHEMATICS

### POWERS OF TEN

The technique of using powers of 10 can greatly simplify mathematical calculations. In the powers of 10 system, a very large or very small number is expressed as a quantity between one and 10 and the appropriate positive or negative power of 10. The value and sign of the exponent are determined by the number of places and the direction the decimal point is moved.

Examples:

$$3{,}000{,}000 = 3 \times 10^{6}$$

$$51{,}000 = 5.1 \times 10^{4}$$

$$0.005 = 5 \times 10^{-3}$$

$$0.00000047 = 4.7 \times 10^{-7}$$

Study the information in figure 1.

| NUMBER | POWER OF TEN | PREFIX | SYMBOL |
|---|---|---|---|
| 1 000 000 000 000 | $10^{12}$ | tera | T |
| 1 000 000 000 | $10^{9}$ | giga | G |
| 1 000 000 | $10^{6}$ | mega | M |
| 1 000 | $10^{3}$ | kilo | k |
| 100 | $10^{2}$ | hecto | h |
| 10 | $10^{1}$ | deka | da |
| 0.1 | $10^{-1}$ | deci | d |
| 0.01 | $10^{-2}$ | centi | c |
| 0.001 | $10^{-3}$ | milli | m |
| 0.000 001 | $10^{-6}$ | micro | $\mu$ |
| 0.000 000 001 | $10^{-9}$ | nano | n |
| 0.000 000 000 001 | $10^{-12}$ | pico | p |

Figure 1

Prefixes and symbols are also used to express very large or very small numbers.

Examples:

1,000,000 units = 1 megaunit

20,000 units = 20 kilounits

0.004 units = 4 milliunits

0.0000056 units = 5.6 microunits

Exponents are handled according to the following rules:

When multiplying numbers, add the exponents.

When dividing numbers, subtract the exponent in the denominator from the exponent in the numerator.

When squaring a number, double the exponent.

When obtaining a square root, halve the exponent.

Examples:

$$1{,}000{,}000 \times 1{,}000 = 1 \times 10^{6} \times 1 \times 10^{3}$$

$$= 1 \times 10^{9}$$

$$47{,}000 \times 0.056 = (4.7 \times 10^{4}) \times (5.6 \times 10^{-2})$$

$$= 26.32 \times 10^{2}$$

$$= 2.632 \times 10^{3}$$

$$\frac{50{,}000}{2{,}500} = \frac{5 \times 10^{4}}{2.5 \times 10^{3}}$$

$$= 2 \times 10^{1}$$

$$\frac{0.0075}{0.15} = \frac{7.5 \times 10^{-3}}{1.5 \times 10^{-1}}$$

$$= 5 \times 10^{-2}$$

**EQUATIONS**

An equation is a mathematical statement that two quantities are equal. The following axioms can be applied to any equation without changing the equality:

1. Adding the SAME number to BOTH sides.

2. Subtracting the SAME number from BOTH sides.

3. Multiplying BOTH sides by the SAME number.

4. Dividing BOTH sides by the SAME number.

5. Terms equal to a third term are equal to each other.

6. Raising BOTH sides to the SAME power.

7. Taking the SAME root of BOTH sides.

Frequently formulas must be rearranged to find a quantity in terms of the other quantities involved.

Examples:

$I = \frac{E}{R}$ Solve for R.

$R \times I = \frac{E}{R} \times R$ Multiply by R.

$RI = E$ Simplify.

$\frac{RI}{I} = \frac{E}{I}$ Divide by I.

$R = \frac{E}{I}$ Simplify.

$X_C = \frac{1}{2\pi fC}$ Solve for f.

$f \times X_C = \frac{1}{2\pi fC} \times f$ Multiply by f.

$\frac{f \times X_C}{X_C} = \frac{1}{2\pi CX_C}$ Divide by $X_C$.

$f = \frac{1}{2\pi CX_C}$ Simplify.

## MODULE 4

## DIRECT CURRENT AND VOLTAGE

### CONDUCTORS AND INSULATORS

The electrical conductivity of a material depends on its atomic structure, which determines if it is a conductor, a semi-conductor, or an insulator. A material which allows electrons to move from atom to atom is said to have free electrons and is a good conductor. A material which does not allow electrons to move from atom to atom is said to have no free electrons and is a good insulator.

Examples of good conductors are silver, copper, gold, and aluminum. Examples of good insulators are rubber, plastic, and glass. Silicon and germanium are examples of two common semi-conductors used in solid state devices.

### CURRENT AND VOLTAGE

Negatively (-) charged electrons revolve around the positively (+) charged protons of the atoms within a material. These electrons become an electric current when brought under the influence of an external force or charge. The movement of these electrons conforms to the law of charges, which states that LIKE CHARGES REPEL and UNLIKE CHARGES ATTRACT. When a material has a deficiency of electrons it has a positive charge. A surplus of electrons produces a negative charge.

When the charges are connected together through a conductor they exert a pressure on the free electrons of the conductor and cuase them to move from the negative charge to the positive charge. This electron movement is known as CURRENT and is measured in amperes (A). The electrical symbol for current is the letter I.

In order to maintain current flow in a conductor, the positive and negative charges, or difference of potential, must be maintained. This pressure is known as electromotive force (EMF) and is measured in VOLTS (V). The electrical symbol for electromotive force is the letter E.

## SOURCES OF ELECTROMOTIVE FORCE

EMF may be produced by mechanical action (generator), chemical action (battery), thermoelectric effect (thermocouple), photoelectric (television camera), and piezoelectric (crystal microphone).

## MODULE 5

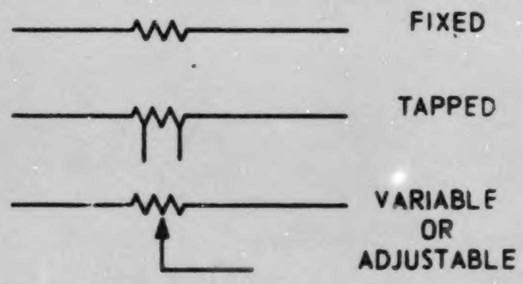
## RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

### RESISTANCE AND RESISTORS

Resistance (R) is the opposition to current flow and the unit of measure is the ohm (Ω). When 1 volt causes 1 ampere of current to flow, the opposition is 1 ohm (1 Ω).

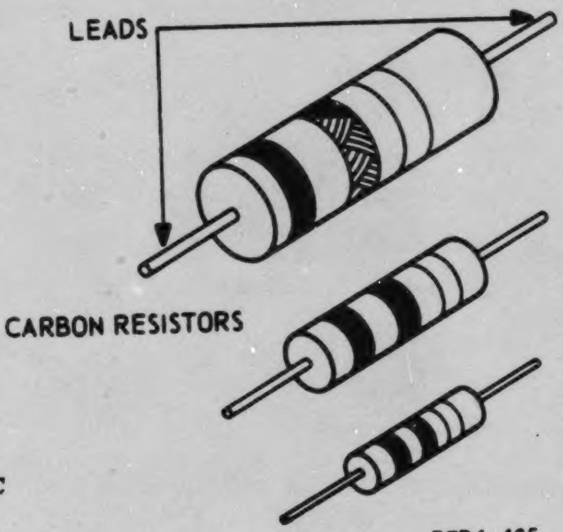
Resistors may be classified into three general types: fixed, tapped, and variable. Figure 1 shows the symbol for each.

Carbon resistors are constructed from graphite and a binder. Wires are attached to the graphite and insulating material is molded around the graphite. See figure 2A. Fixed wire resistors are merely resistance wire wound on an insulating material. See figure 2B.



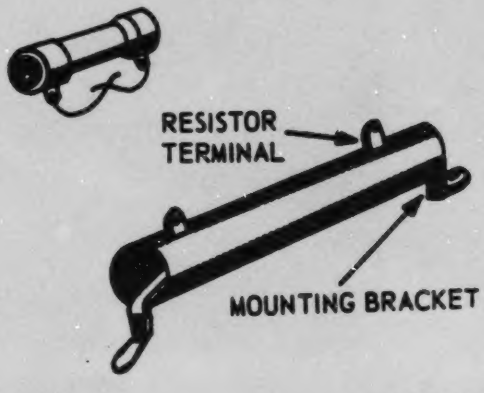
REP4-488

Figure 1



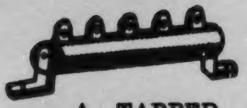
REP4-485

Figure 2A

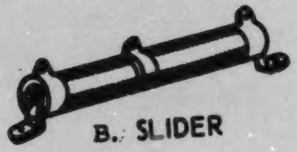


REP4-482

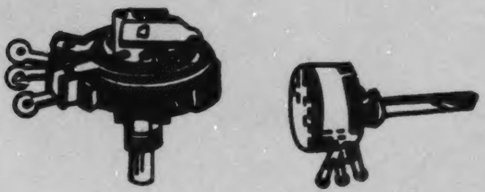
Figure 2B



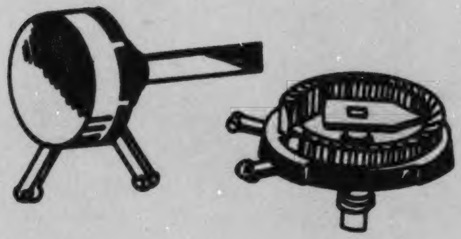
A. TAPPED



B. SLIDER



C. POTENTIOMETER



D. RHEOSTAT

Figure 3

A tapped resistor is a wire-wound resistor with a tap or taps. See figure 3A. A slide tap is shown in figure 3B. A variable resistor could have carbon or resistance wire for the resistive element. See figure 3C and figure 3D. Notice that the potentiometer has three terminals while the rheostat has only two. A rheostat is used to get a change in current. A potentiometer is used to get a change in voltage.

SCHEMATIC SYMBOLS

Figure 4 shows many schematic symbols you should become familiar with.

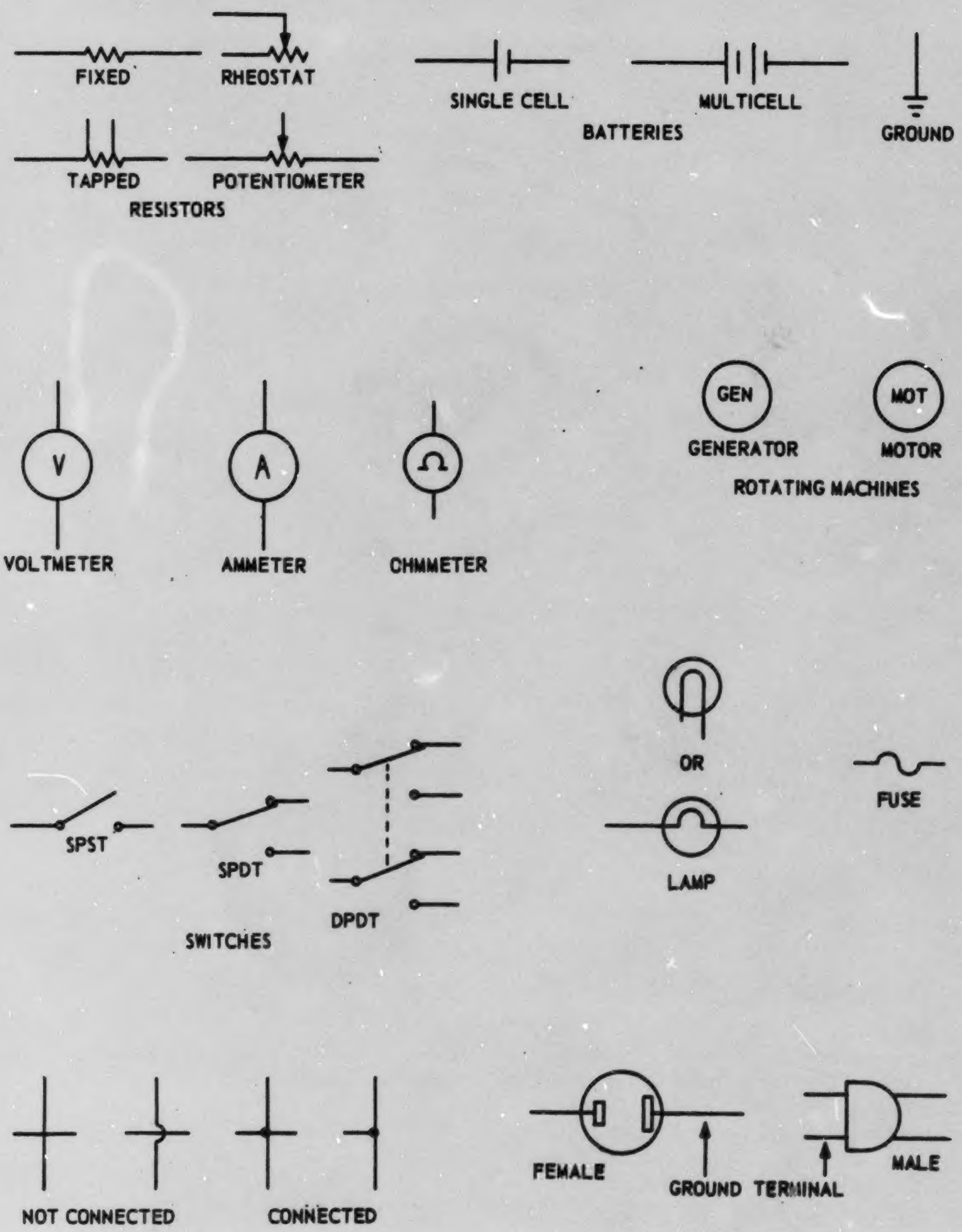
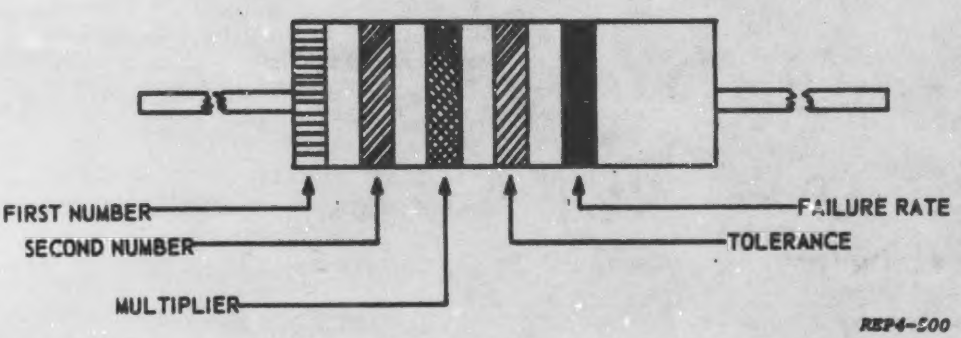

FIXED
RHEOSTAT
TAPPED
POTENTIOMETER
RESISTORS
SINGLE CELL
MULTICELL
BATTERIES
GROUND
V
A
Ω
VOLTMETER
AMMETER
OHMMETER
GEN
MOT
GENERATOR
MOTOR
ROTATING MACHINES
SPST
SPDT
DPDT
SWITCHES
OR
LAMP
FUSE
NOT CONNECTED
CONNECTED
CROSSED WIRES
FEMALE
GROUND TERMINAL
MALE
POLARIZED CONNECTOR

Figure 4

## COLOR CODE

Most resistors will be color coded. The code type covered here is the END-TO-CENTER band system. Three bands of color are used to indicate the value of the tolerance. When not used, the tolerance is 20%. The fifth band, when used, indicates the failure rate. See figure 5.



REP4-500

### COLOR CODES FOR PART IDENTIFICATION MARKING

| COLOR | PART | SIGNIFICANT FIGURES OF ELECTRICAL VALUE | | | TOLERANCE | FAILURE RATE PER 1000 HRS |
|---|---|---|---|---|---|---|
| | | 1st Number | 2nd Number | Multiplier | | |
| Black | Capacitor | 0 | 0 | 1 | ±20% | L 5% |
| Brown | --- | 1 | 1 | 10 | ± 1% | M 1% |
| Red | --- | 2 | 2 | 100 | ± 2% | P 0.1% |
| Orange | --- | 3 | 3 | 1000 | --- | R 0.01% |
| Yellow | --- | 4 | 4 | 10000 | --- | S 0.001% |
| Green | Diode | 5 | 5 | 100000 | --- | T 0.0001% |
| Blue | --- | 6 | 6 | 1000000 | --- | |
| Violet | --- | 7 | 7 | 10000000 | --- | |
| Gray | --- | 8 | 8 | | --- | |
| White | --- | 9 | 9 | | --- | |
| Gold | --- | - | - | 0.1 | ± 5% | |
| Silver | Coil | - | - | 0.01 | ±10% | |

Figure 5

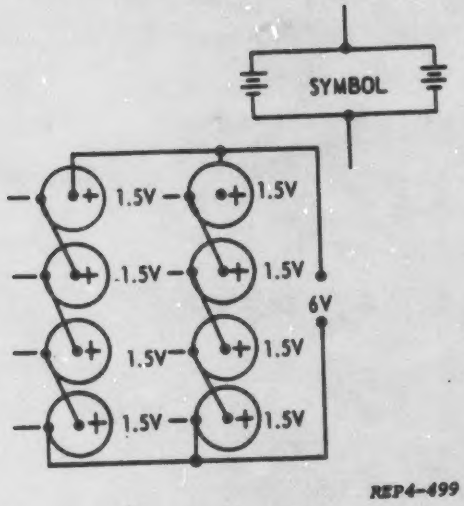


Figure 6

## BATTERY CELLS IN SERIES AND PARALLEL

When a battery of cells is used as a source of EMF, the desired output voltage and current carrying ability is determined by how the cells are connected together. Voltages of all cells in series will add together. When connected in parallel, the output is the same, but the current available will be doubled when two cells are in parallel. Figure 6 shows a series parallel hookup of eight 1.5-volt cells to get 6 volts out.

NOTICE: For the series connection, the negative terminal of one cell is connected to the positive terminal on the next cell. The voltage will add up to 6 volts. The parallel connection is made by connecting the two positive terminals together and the two negative terminals together for the two series sets. The parallel connection will double the available current value.

## MODULE 6

## MULTIMETER USES

### RESISTANCE MEASUREMENT

To use the PSM-6 as an OHMMETER, place the FUNCTION switch to the OHMS position. Touch the leads together and adjust the OHMS ZERO control for a reading of 0 on the ohms scale.

There are five ranges for resistance measurements, each designated by the symbol Ω (omega).

The test leads are connected across the component to be checked and the range is selected to cause the pointer to indicate as near as possible to the center or right side of the scale. The reading from the OHMS scale is then multiplied by the number found at the particular RANGE switch setting.

THE OHMMETER SHOULD NEVER BE CONNECTED TO AN OPERATING CIRCUIT.

### DC VOLTAGE MEASUREMENT

To use the PSM-6 to measure DC voltage, place the FUNCTION switch to DC V 20 K Ω/V.

There are seven positions of the RANGE switch. They are from .5 volts to 1000 volts and indicate full scale readings on the black DC volts scale.

The RED test lead must be connected to the positive (+) side of the component to be measured, and the BLACK lead must be connected to the negative (-) side of the component. A reading off scale to the left indicates that you have incorrectly connected the leads.

TO MEASURE AN UNKNOWN VOLTAGE, ALWAYS START ON THE HIGHEST RANGE. DAMAGE TO THE METER MAY RESULT IF EXCESSIVE VOLTAGE IS APPLIED.

### DIRECT CURRENT MEASUREMENT

To use the PSM-6 to measure current, place the FUNCTION switch to the DC MA position.

Direct current up to 1000 milliamps (one amp) may be read on the black scale.

Current is measured by placing the meter in series with the circuit under test. The current must pass through the meter in the proper direction, therefore, polarities must be observed. The BLACK lead must be connected to the more negative point and the RED lead must be connected to the more positive point to be measured.

TO MEASURE AN UNKNOWN CURRENT, ALWAYS START ON THE HIGHEST RANGE. DAMAGE TO THE METER MAY RESULT IF EXCESSIVE CURRENT IS APPLIED.

### AC VOLTAGE MEASUREMENT

To use the PSM-6 to measure AC voltage, place the FUNCTION switch to the AC V position.

There are seven positions on the RANGE switch. They are from .5 volts to 1000 volts and indicate full scale readings on the blue scale for AC voltage.

To measure AC voltage connect the test leads directly across the component to be checked. Polarity of the leads is unimportant.

TO MEASURE AN UNKNOWN VOLTAGE, ALWAYS START ON THE HIGHEST RANGE. DAMAGE TO THE METER MAY RESULT IF EXCESSIVE VOLTAGE IS APPLIED.

## MODULE 7

## SERIES RESISTIVE CIRCUITS

### CIRCUIT REQUIREMENTS

In order to have a practical DC circuit, certain conditions must exist. There must be a power source, a load device, and a conductor. All of these components must be connected in a manner to provide a complete path for current flow from the negative terminal of the source to the positive terminal of the source.

### OHM's LAW

In any circuit, current (I), voltage(E), and resistance (R) conforms to OHM'S LAW which states that, current in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance.

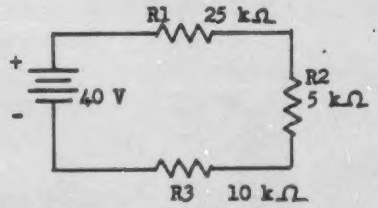
Or: $I = \frac{E}{R}$

Therefore: $R = \frac{E}{I}$

And: $E = IR$

### SERIES CIRCUIT ANALYSIS

In a series circuit, all components are connected end-to-end and there is only one path for current flow. Study the circuit shown.



In a series circuit, total resistance is found by adding the individual resistances.

Or: $R_t = R1 + R2 + R3 + \ldots\ldots$

Then: $R_t = 25\text{ k}\Omega + 5\text{ k}\Omega + 10\text{ k}\Omega$

$R_t = 40\text{ k}\Omega$

To find current, use Ohm's Law.

Or: $I = \frac{E_a}{R_t}$

Then: $I = \frac{40\text{ V}}{40\text{ k}\Omega}$

$I = 1 \times 10^{-3}$ A or 1 mA

When current flows through a load device, heat is produced and electrical power is consumed or dissipated. The power dissipated (P) is measured in watts(W) and is calculated from the following formulas:

$$P = I^2R$$

$$P = \frac{E^2}{R}$$

$$P = IE$$

Find the power dissipated in figure 1 on page 9.

$$P = I^2R$$

$$P = (1 \times 10^{-3})^2 \times (40 \times 10^3)$$

$$P = (1 \times 10^{-6}) \times 40 \times 10^3$$

$$P = 40 \times 10^{-3} \text{ W or } .04 \text{ W}$$

## MODULE 8

## PARALLEL RESISTIVE CIRCUITS

### CIRCUIT ANALYSIS

A parallel circuit is a circuit in which two or more load devices are connected across one power source. A parallel circuit always has more than one path for current flow. Study the circuit shown.

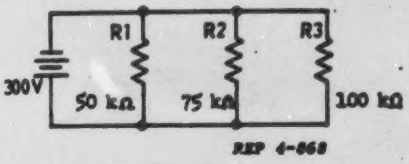


Figure 1

The voltage applied to each resistor or circuit branch is the same.

Or: $E_a = E_{R1} = E_{R2} = E_{R3} = \dots$

Total current is the sum of all of the branch currents.

Or: $I_t = I_{R1} + I_{R2} + I_{R3} + \dots$

The resistance of each branch is different, therefore, each branch current will be different.

The two formulas are confirmed by Kirchhoff's Laws for current and voltage, which state:

1. The algebraic sum of the instantaneous currents at any junction is zero. The current leaving any junction of conductors must equal the current that entered that junction.

2. The algebraic sum of the instantaneous voltages around any closed loop is zero. The sum of the voltage drops around any one loop (current path) must equal the applied voltage. In the figure, there are three current paths.

These two laws in conjunction with Ohm's law are used to solve all resistive networks.

Total resistance of a parallel circuit is found by using one of the following methods:

1. For three or more resistors of different value.

$$R_t = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \dots}$$

2. For two resistors of different value.

$$R_t = \frac{R1 \times R2}{R1 + R2}$$

3. For two or more resistors of equal value.

$$R_t = \frac{R}{N}$$

Where N equals the number of resistors.

4. For two or more resistors, using the assumed voltage method:

a. Assign a convenient value for the applied voltage.

b. Calculate the current in each branch, using the assumed voltage.

c. Add the branch currents to obtain total current.

d. Calculate total resistance, using the assumed voltage and total current.

For the circuit in figure 1, find: $R_t$, $I_t$, and $P_t$.

$$I_t = \frac{E_a}{R1} + \frac{E_a}{R2} + \frac{E_a}{R3}$$

$$I_t = 13 \text{ mA}$$

$$R_t = \frac{E_a}{I_t}$$

$$R_t = 23 \text{ k}\Omega$$

$$P_t = E_a \times I_t$$

$$P_t = 3.9 \text{ W}$$

## RESISTIVE BRIDGE CIRCUITS

A resistive bridge circuit is a type of circuit commonly found in electronic testing and measuring equipment. See figure 2.

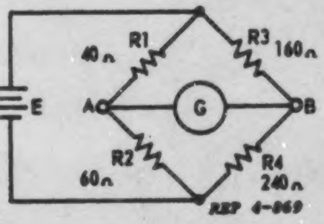


Figure 2

The circuit has two branches for current flow and a microammeter which indicates the magnitude and direction of current. When the following relationships are satisfied, the circuit is BALANCED.

$$\frac{R1}{R2} = \frac{R3}{R4}$$

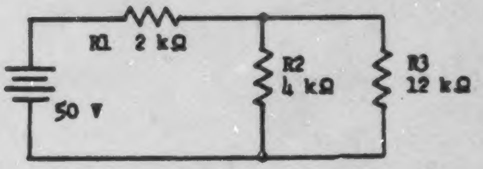
When balanced, the potential difference between points A and B is zero and no current flows through the meter.

To use this circuit to measure resistance, R4 is replaced by the unknown value ($R_x$). The bridge is then brought to balance by substituting known values for R2.

## MODULE 9

## SERIES-PARALLEL RESISTIVE CIRCUITS

A series-parallel resistive circuit has both series and parallel components. See the figure below.



Resistors R2 and R3 are in parallel with each other and in series with R1. In the circuit shown, find $R_t$, $I_t$, and $P_t$.

The equivalent resistance of R2 and R3 in parallel must be found first. Use a formula for resistors in parallel.

$$R_e = \frac{R2 \times R3}{R2 + R3}$$

$$R_e = 3 \text{ k}\Omega$$

Find total resistance using the formula for resistors in series.

$$R_t = R_e + R1$$

$$R_t = 5 \text{ k}\Omega$$

Use Ohm's law to find total current.

$$I_t = \frac{E_a}{R_t}$$

$$I_t = 10 \text{ mA}$$

To find total power use any of the power formulas.

$$P_t = E_a \times I_t$$

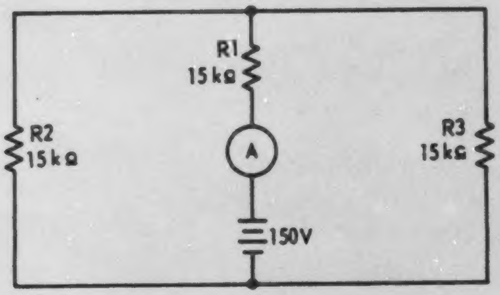
$$P_t = .5\ W$$

## MODULE 10

## TROUBLESHOOTING DC RESISTANCE CIRCUITS

Troubleshooting is a process of locating causes for circuit failures. You should be able to locate open or shorted resistors. An open resistor will have extremely high resistance. For our purposes, an open resistor will be considered to have infinite resistance. A shorted resistor will have zero resistance. An ohmmeter then can be used to check for open or shorted resistors. Before applying the ohmmeter **BE SURE THE POWER IS OFF** and the resistor is isolated from the circuit to prevent parallel paths.

A voltmeter can be used for locating open or shorted resistors. The voltage across an open resistor will be excessive (often the applied voltage) and the voltage across a shorted resistor will be zero volts. Consider the series-parallel circuit shown in figure 1. If R1 would open, the applied voltage would appear across R1. The voltage across R2 and R3 would be zero volts. If R2 were to open, then R1 and R3 would form a simple series voltage divider. R1 and R3 would each drop one half of the applied voltage. If R1 became shorted, the voltage across R1 would be zero volts. The applied voltage would now appear across the parallel combination of R2 and R3. If R2 became shorted, the voltage drop across R2 and R3 would be zero volts. All of the applied voltage would appear across R1.



REP4-1184

Figure 1

An ammeter can be used to locate open or shorted resistors. An open resistor normally decreases total current and a shorted resistor normally increases total current. Refer to the figure and calculate total resistance and total current. Total resistance is 22.5 kΩ and total current is 6.67 mA. If R1 should open, total current would decrease to zero mA. If R2 should open, total current would decrease to 5 mA. If R1 should short, total current will increase to 20 mA. If R2 should short, total current will increase to 10 mA.

In actual practice a combination of the above methods is often used. In any case a complete understanding of the application of Ohm's Law along with the readings obtained with the test equipment will help you locate circuit failure.

## MODULE 11

## ~~AC COMPUTATION AND FREQUENCY SPECTRUM~~

~~In previous lessons, you studied current which flows in one direction only. Now, you are ready to take up current which alternately flows in two directions.~~

## ~~ALTERNATING CURRENT (AC).~~

~~Alternating current is the term applied to current which periodically reverses its direction.~~

~~The sine wave is the most common AC waveform. In fact, the sine wave is so widely used that when we think of AC, we automatically think of the sine wave. Household~~

ATC HO 3AQR3X020-X
Prepared by Keesler TTC
KEP-HO-107

Technical Training

# Electronic Principles (Modular Self-Paced)

## Modules 3-28

## DC, AC, AND RCL CIRCUITS

January 1976

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 6-2800

DO NOT USE ON THE JOB

39

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC HO 3AQR3X020-X
KEP-HO-107
January 1976

## PURPOSE OF TRAINING PUBLICATIONS

Training publications are designed for ATC use only. They are updated as necessary for training purposes, but are NOT to be used on the job as authoritative references in preference to Technical Orders or other official publications.

This particular HANDOUT (HO) is designed to provide guidance to aid you in gaining the knowledges required by the objectives listed in your Guidance Packages for Blocks I, II, and III. This book contains formulas, diagrams, and information on the use of meters. Bring it to class as a reference while you are in Blocks I, II, and III of this course.

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| Use of Ohmmeter | 2 |
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| Transistorized Power Supply | 8 |
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Supersedes Student Handout, KEP 107, 1 September 75. Previous editions may be used.

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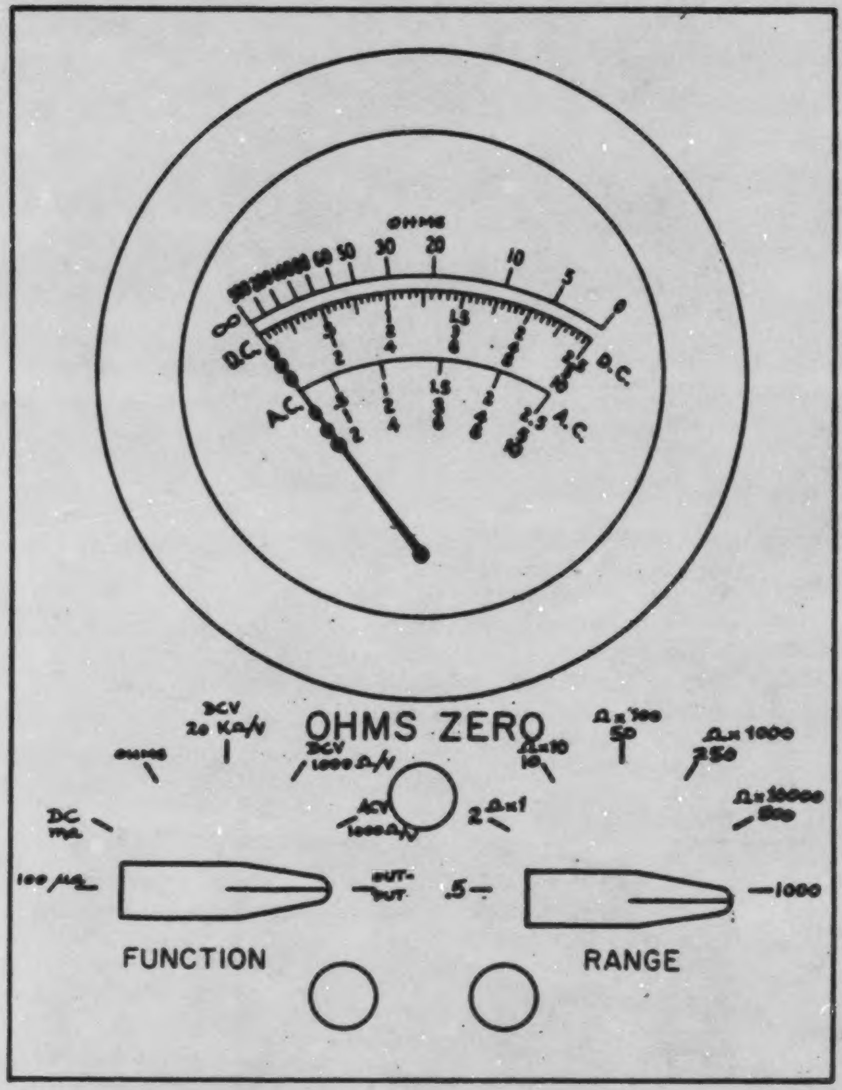
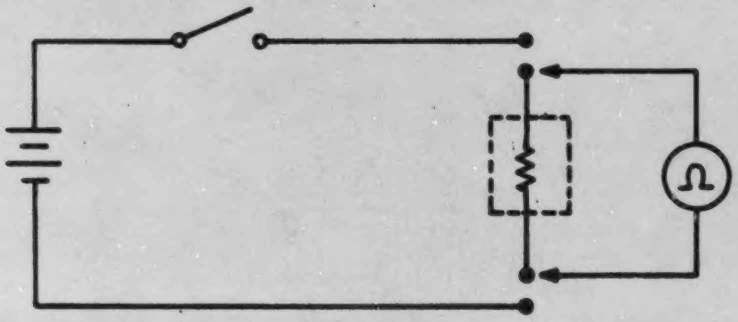


Ohm's Scale --- Green
Volts DC Scale --- Black
Volts AC Scale --- Blue
Current Scale ------Black

## METER READINGS

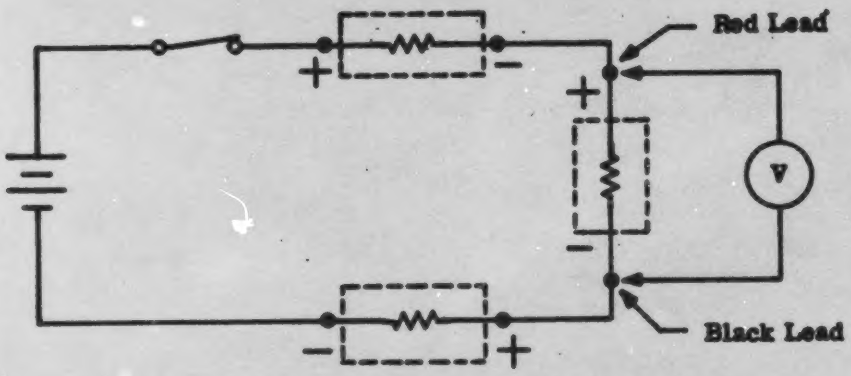
1. Difference in voltage between two consecutive numbers.
2. Number of divisions between two consecutive numbers.
3. Divide step 1 by step 2 - gives the volts per unit.

$$\frac{\text{Volts}}{\text{Division}} = \frac{\text{Nr. Volts}}{\text{Nr. Divisions}}$$



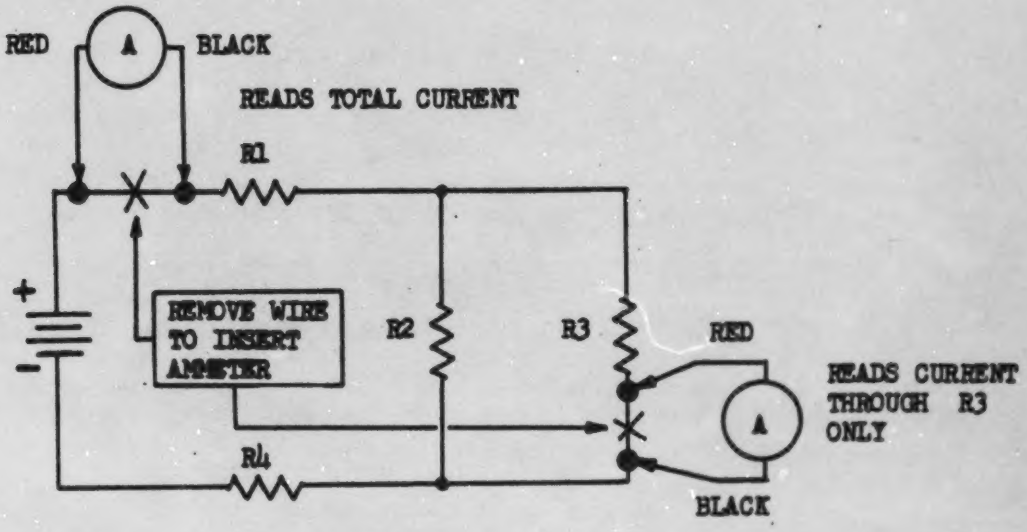
## USE OF OHMMETER

1. Turn power supply off.
2. Isolate individual resistor.
3. Set PSM-6 on proper function and range.
4. Short leads together and ADJUST FOR ZERO OHMS.
5. Connect PSM-6 in parallel with resistor.
6. Read green scale and multiply by range for answer.
7. Turn all switches clockwise when finished.
8. ZERO OHMMETER EVERY TIME RANGE SWITCH IS CHANGED.



## USE OF VOLTMETER

1. Set function to DC volts 20 k ohms/volt.
2. Set range to highest position.
3. Connect the PSM-6 red lead to most positive point and black lead to most negative point of the component to measure its voltage drop.
4. Take reading on black scale, observing proper range and scale.



## USE OF AMMETER

1. Set the FUNCTION switch on DC MA.

2. Set RANGE switch to highest range.

3. Determine where in the circuit the ammeter is to be inserted. Remember: The circuit must be broken (opened) and the ammeter placed in series with the circuit.

4. Remove the wire that is at the point where the ammeter is to be inserted.

5. Replace the wire with the ammeter. The RED lead to the positive and the BLACK lead to the negative point. The ammeter is now connected in series with the circuit where current is to be measured.

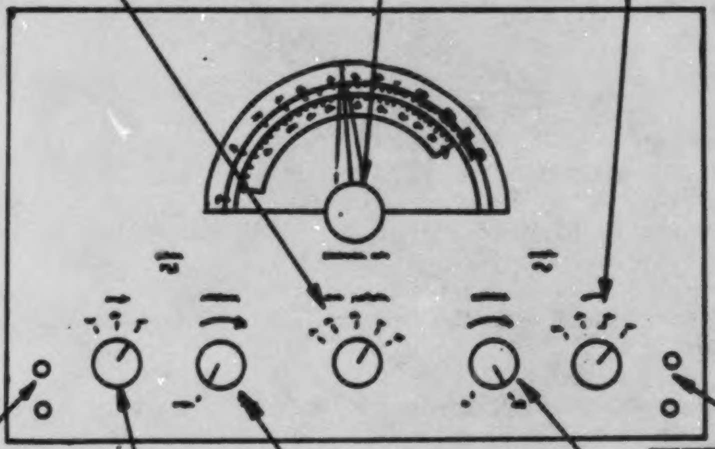
6. Read the black scale and multiply by the RANGE switch setting to obtain the current value.

## SINE-SQUARE WAVE GENERATOR

1. FREQUENCY (cps): The frequency of the signal from this generator is equal to the setting of this control multiplied by the setting of the FREQ MULTIPLIER switch.

2. FREQ MULTIPLIER: Multiply the number this switch is set to by the number to which the FREQUENCY point is set, to determine the output frequency.

3. RANGE: This switch is the coarse adjustment for the sine wave amplitude, and has four ranges: .01 V, .1 V, 1 V, and 10 V.



8. SQUARE WAVE output terminals.

4. SINE WAVE output terminals.

5. AMPLITUDE: This control is a fine adjustment of the sine wave amplitude from 0 volts to the maximum voltage of the RANGE setting.

7. RANGE: This switch is the coarse adjustment for the square wave amplitude and has three ranges: .1 V, 1 V, and 10 V.

6. AMPLITUDE: This control is a fine adjustment of the square wave signal from 0 volts to the maximum voltage of the RANGE setting. This switch is also used to turn the generator ON and OFF.

# SINE-SQUARE WAVE GENERATOR

## Operating Procedures

### SINE WAVE OUTPUT

1. Set all controls fully CCW
2. Plug power cord into 110 volt source and rotate the square wave AMPLITUDE control CW to turn the generator ON.
3. Set the FREQ MULTIPLIER switch to the range required by the laboratory exercise.
4. Set the FREQUENCY (CPS) control to a setting which when multiplied by the FREQ MULTIPLIER setting will equal the desired output frequency.
5. Connect the SINE WAVE output to the circuit under test.
6. Set the sine wave amplitude RANGE switch to the value required by the laboratory exercise.
7. Adjust the sine wave AMPLITUDE control to obtain the exact amplitude required.

### SQUARE WAVE OUTPUT

1. Set all controls fully CCW.
2. Plug power cord into 110 volt source and rotate the square wave AMPLITUDE control CW to turn the generator ON.
3. Set the FREQ MULTIPLIER switch to the range required by the laboratory exercise.
4. Set the FREQUENCY (CPS) control to a setting which when multiplied by the FREQ MULTIPLIER setting will equal the desired output frequency.
5. Connect the SQUARE WAVE output to the circuit under test.
6. Set the square wave amplitude RANGE switch to the value required by the laboratory exercise.
7. Adjust the square wave AMPLITUDE control to obtain the exact amplitude required.

## RADIO FREQUENCY SIGNAL GENERATOR

This radio frequency signal generator is a laboratory type instrument intended to provide RF signals for laboratory exercises.

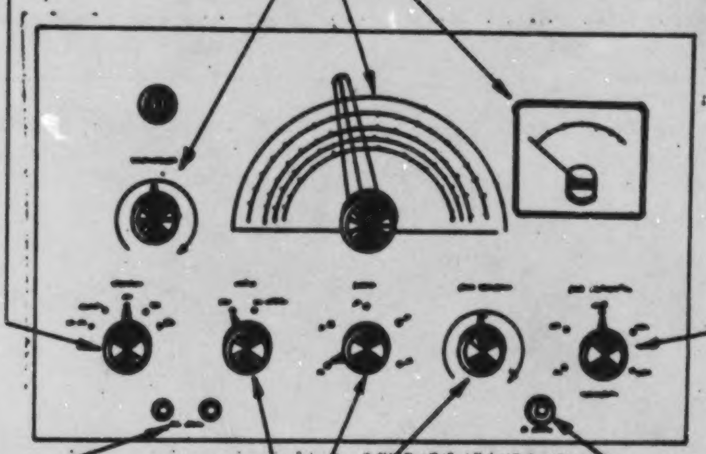
**FREQUENCY SCALE:** Used to select the exact frequency desired. RF carrier frequency is read directly from the scale selected by the RANGE switch.

**MODULATION:** Used to set the degree or percent of modulation from zero to 50%. The percent of modulation is read on the panel meter.

**PANEL METER:** Displays percent of modulation or the amplitude of the RF carrier in microvolts.

**FUNCTION:** Used to select continuous wave or modulated output. Modulation may be from an internal 400 cycle audio generator or from an external source. Turns generator ON.

**STEP ATTENUATOR:** Used to select the amplitude of the RF output and indicates the correct meter multiplier. Five selections cover from 5 to 100 k microvolts.



**AUDIO OUT:** External Modulation signal may be applied here to modulate the RF output. A 400 Hz audio signal output may be taken from here when the FUNCTION switch is in AUD position.

**RF OUTPUT:** Output terminal for the modulated or unmodulated RF signal. Output impedance is 50 ohms. Frequency is variable from 100 kHz to 30 MHz and amplitude is variable from 5 microvolts to 100 k microvolts.

**METER:** Used to select the signal to be displayed on the meter. The percent of modulation or the amplitude of the RF carrier may be monitored.

**FINE ATTENUATOR:** Used to vary the amplitude of the RF output between the steps provided by the STEP ATTENUATOR.

**RANGE:** Used to select the desired RF frequency range. Five selections cover from 100 kHz to 30 MHz.

## RADIO FREQUENCY SIGNAL GENERATOR

### Operating Procedures

1. Set all controls fully CCW.

2. Plug power cord into 110 volt power source.

3. Rotate the FUNCTION switch to MCW.

4. Rotate the RANGE switch to the desired band of frequencies.

5. Set the FREQUENCY SCALE indicator to the exact frequency desired.

6. Set the METER switch to MOD and adjust the MODULATION control for the desired percent of modulation as indicated on the PANEL METER.

7. Set the METER switch to RF CARRIER.

8. Connect the RF OUTPUT to the circuit under test.

9. Set the STEP ATTENUATOR to the desired amplitude range.

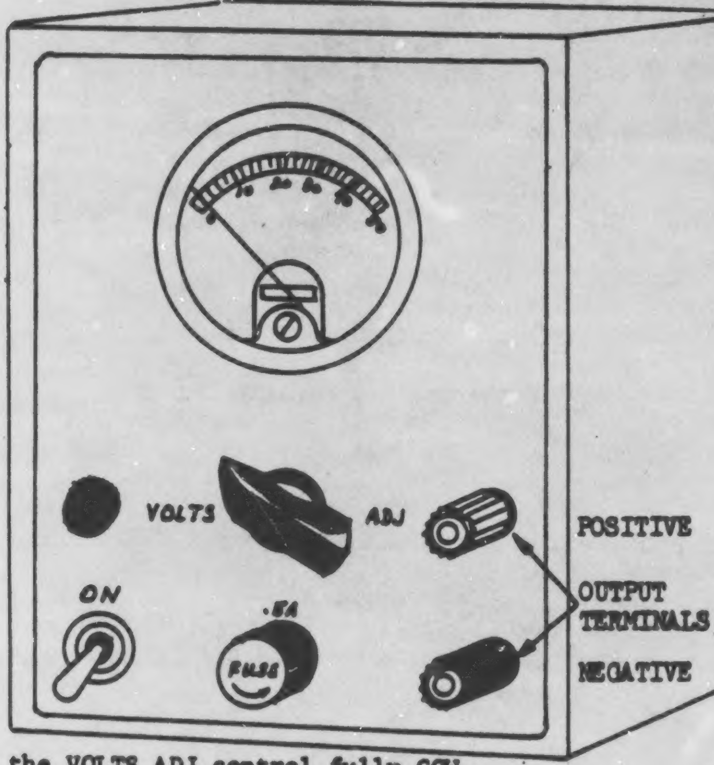
10. Rotate the FINE ATTENUATOR to the desired exact amplitude as indicated on the PANEL METER.

11. To obtain an unmodulated RF signal, place the FUNCTION switch to CW and perform steps 7 through 10 above.

12. To externally modulate the RF signal, place the FUNCTION switch to EXT and connect an external signal source to the EXT MOD terminals. Perform steps 6 through 10 above.

## TRANSISTORIZED POWER SUPPLY

This power supply is designed to power the many trainers used in Electronic Principles. It will provide 0-40 volts DC and up to 150mA.



1. Turn the VOLTS ADJ control fully CCW

2. Connect the power supply to the trainer as directed by the laboratory excercise. Observe polarity.

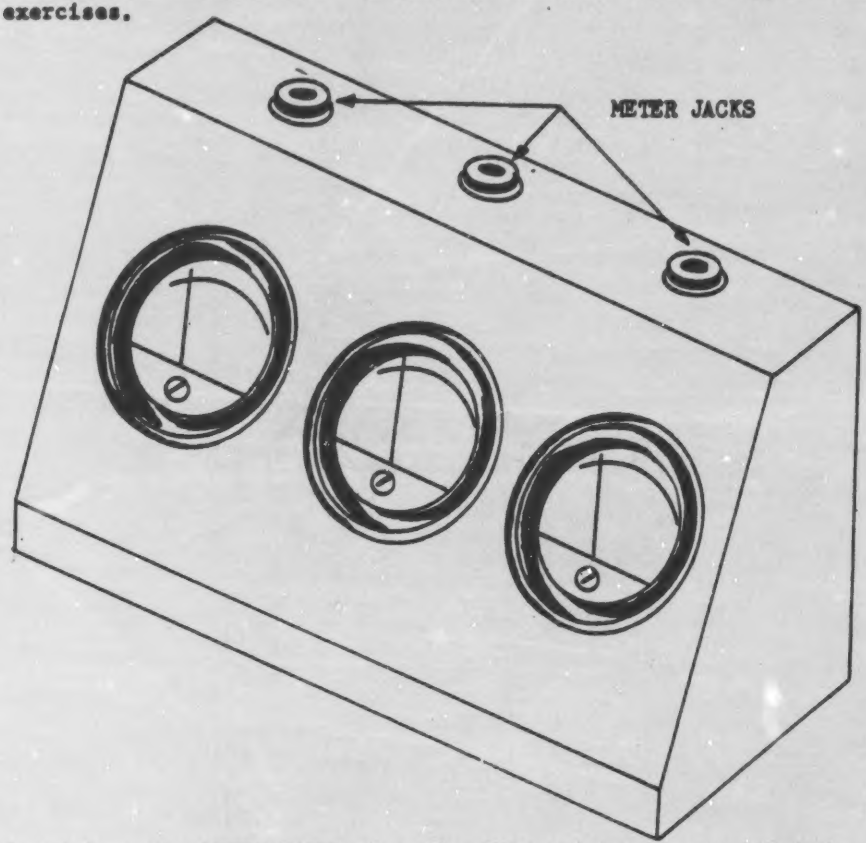
   NOTE: The power supply may be connected to the trainer using the terminals on the front or the cable on the rear of the power supply.

3. Plug the power cord of the power supply into a 110 volt power source.

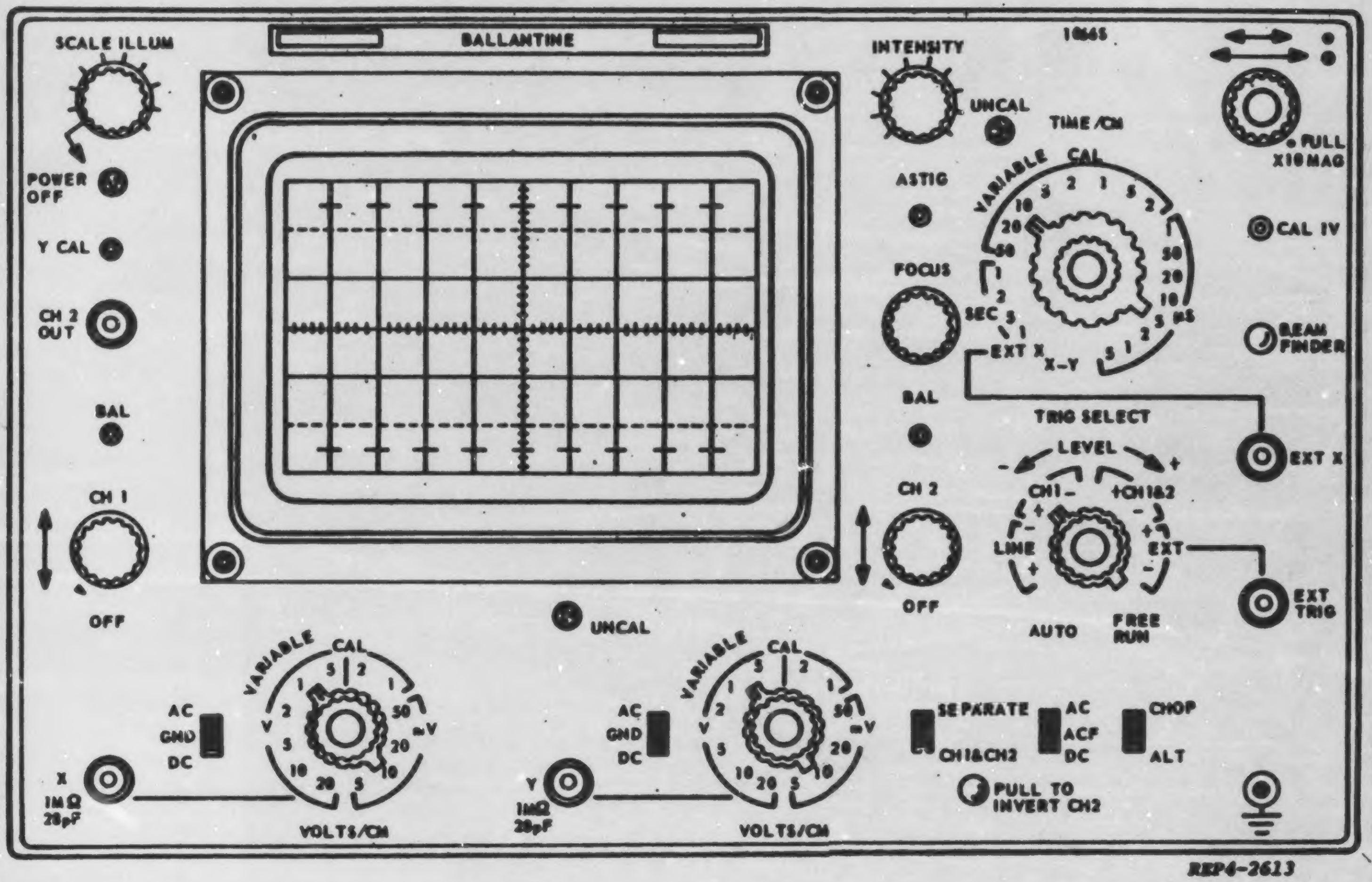
4. Turn the power supply ON and adjust the VOLTS ADJ until the panel meter indicates the voltage called for in the laboratory exercise.

## METER PANEL

This METER PANEL consists of three selected meter movements. The various' meters will measure DC current from 10mA to 500mA full scale or AC current from 1 mA to 50 mA full scale. This METER PANEL is used to support the laboratory exercises.



1. Select the METER PANEL that has the meter ranges required for the laboratory exercise.
2. Make a visual inspectionof the fuses located inside the case and directly behind each meter movement.
3. Plug the test leads into the jack located directly above the selected meter movement.
4. Connect the test leads in series with the circuit under test. Observe proper polarity for the DC meters.


SCALE ILLUM
BALLANTINE
INTENSITY
1065
POWER OFF
Y CAL
CH 2 OUT
BAL
CH 1
OFF
UNCAL
TIME/CM
ASTIG
VARIABLE
CAL
FOCUS
SEC
MS
EXT X
X-Y
FULL X10 MAG
CAL 1V
BEAM FINDER
TRIG SELECT
LEVEL
CH1
CH1&2
LINE
EXT
AUTO
FREE RUN
EXT X
EXT TRIG
CH 2
OFF
UNCAL
AC
GND
DC
V
mV
VOLTS/CM
X 1MΩ 28pF
Y 1MΩ 28pF
SEPARATE
CH1&CH2
AC
ACF
DC
CHOP
ALT
PULL TO INVERT CH2
REP4-2613

USM-398

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## ELECTROSTATICS

$$F = \frac{Q_1 Q_2}{d^2}$$

F = Force in dynes     $Q_1$ = Charge 1 in esu
d = Distance in cm     $Q_2$ = Charge 2 in esu

## DIRECT CURRENT

$E = IR$     $I = \frac{E}{R}$     $R = \frac{E}{I}$     $P = IE = I^2 R = \frac{E^2}{R}$

## SERIES CIRCUITS

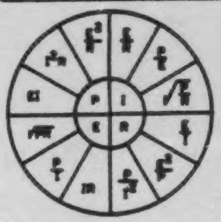
$I_t = I_1 = I_2 = I_3 = \ldots$     $I_t = \frac{E_a}{R_t}$

$E_a = E_{R1} + E_{R2} + E_{R3} + \ldots$     $E_a = I_t R_t$

$R_t = R1 + R2 + R3 + \ldots.$     $R_t = \frac{E_a}{I_t}$

$P_t = P_{R1} + P_{R2} + P_{R3} + \ldots.$     $P_t = E_a I_t$

OHM'S LAW FORMULAS FOR DC CIRCUITS



## PARALLEL CIRCUITS

$E_a = E_1 = E_2 = E_3 = \ldots.$     $E_a = I_t R_t$

$I_t = I_1 + I_2 + I_3 + \ldots$     $I_t = \frac{E_a}{R_t}$

$$R = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots} \qquad R = \frac{E_a}{I_t} = \frac{R1 \times R2}{R1 + R2} = \frac{R}{N}$$

(two resistors)     (equal) (resistors)

$P_t = P_{R1} + P_{R2} + P_{R3} + \ldots$     $P_t = I_t E_a$

## BALANCED BRIDGE

$$\frac{R1}{R2} = \frac{R3}{R4}$$

## SINE WAVE CONVERSION FACTORS

$$E_{eff} = .707\ E_{peak} = 1.11\ E_{ave}$$

$$E_{ave} = .637\ E_{peak} = .9\ E_{eff}$$

$$E_{peak} = 1.414\ E_{eff} = 1.57\ E_{ave}$$

$$E_{peak\ to\ peak} = 2\ E_{eff} = 2.828\ E_{eff}$$

## METER MOVEMENTS

### Ammeters

$$R_s = \frac{I_m R_m}{I_t - I_m}$$

$R_s$ = Shunt Resistor

$I_t$ = Desired full scale current reading

$I_m$ = Full scale current of meter movement

$R_m$ = Resistance of meter movement

### Voltmeters

$$R_x = \frac{E_{fs}}{I_m} - R_m$$

$R_x$ = Multiplier Resistor

$I_m$ = Full scale current of meter movement

$E_{fs}$ = Desired full scale voltage reading

$R_m$ = Resistance of meter movement

## WAVELENGTH AND FREQUENCY

$$\lambda = \frac{V}{f} = Vt \qquad f = \frac{V}{\lambda} = \frac{1}{t} \qquad t = \frac{1}{f}$$

$\lambda$ = Wavelength in meters

V = velocity of $300 \times 10^6$ meters/sec

t = Time in seconds

f = Frequency in hertz

## INDUCTANCE AND INDUCTIVE REACTANCE

$L = \frac{N^2 A \mu k}{l}$ $X_L = 2\pi fL = 6.28\ fL$

Series:

$E_a = E_{L1} + E_{L2} + E_{L3} + \ldots$ $E_a = I_t X_{Lt}$

$I_t = I_{L1} = I_{L2} = I_{L3} = \ldots$ $I_t = \frac{E_a}{X_{Lt}}$

$L_t = L1 + L2 + L3 + \ldots$

$X_{Lt} = X_{L1} + X_{L2} + X_{L3} + \ldots$ $X_{Lt} = \frac{E_a}{I_t}$

Parallel:

$E_a = E_{L1} = E_{L2} = E_{L3} = \ldots$ $E_a = I_t X_{Lt}$

$I_t = I1 + I2 + I3 + \ldots$ $I_t = \frac{E_a}{X_{Lt}}$

$L_t = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3}} + \ldots$ $L_t = \frac{L1 \times L2}{L1 + L2}$ (two inductors) $L_t = \frac{L}{N}$ (equal inductors)

$X_{Lt} = \frac{1}{\frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}}} + \ldots$ $X_{Lt} = \frac{X_{L1} \times X_{L2}}{X_{L1} + X_{L2}}$ (two reactances) $X_{Lt} = \frac{X_L}{N}$ (equal reactances)

## TRANSFORMERS

$\frac{E_p}{E_s} = \frac{N_p}{N_s}$ $\frac{E_p}{E_s} = \frac{I_s}{I_p}$ $\frac{E_p}{E_s} = \frac{\sqrt{Z_p}}{\sqrt{Z_s}}$ $\frac{Z_p}{Z_s} = \frac{E_p^{\ 2}}{E_s^{\ 2}} = \frac{I_s^{\ 2}}{I_p^{\ 2}} = \frac{(N_p)^2}{(N_s)^2}$

$\frac{I_s}{I_p} = \frac{N_p}{N_s}$

$E_p$ = Primary voltage $E_s$ = Secondary voltage
$N_p$ = Primary turns $N_s$ = Secondary turns
$I_p$ = Primary current $I_s$ = Secondary current
$Z_p$ = Primary impedance $Z_s$ = Secondary impedance

## CAPACITANCE AND CAPACITIVE REACTANCE

$C = \frac{kA}{d}$ $\quad$ $Q = CE$ $\quad$ $X_C = \frac{1}{2\pi fC} = \frac{.159}{fC}$

**Series:**

$E_a = E_{C1} + E_{C2} + E_{C3} + \ldots$ $\quad$ $E_a = I_t X_{C_t}$

$I_t = I_{C1} = I_{C2} = I_{C3} = \ldots$ $\quad$ $I_t = \frac{E_a}{X_{C_t}}$

$C_t = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C2}} + \ldots$ $\quad$ $C_t = \frac{C1 \times C2}{C1 + C2}$ $\quad$ $C_t = \frac{C}{N}$

(two capacitors) $\quad$ (equal capacitors)

$X_{C_t} = X_{C1} + X_{C2} + X_{C3} + \ldots$ $\quad$ $X_{C_t} = \frac{E_a}{I_t}$

**Parallel:**

$E_a = E_{C1} = E_{C2} = E_{C3} = \ldots\ldots$ $\quad$ $E_a = I_t X_{C_t}$

$I_t = I_{C1} + I_{C2} + I_{C3} + \ldots$ $\quad$ $I_t = \frac{E_a}{X_{C_t}}$

$C_t = C1 + C2 + C3 + \ldots$

$X_{C_t} = \frac{1}{\frac{1}{X_{C1}} + \frac{1}{X_{C2}} + \frac{1}{X_{C3}}} + \ldots$ $\quad$ $X_{C_t} = \frac{X_{C1} \times X_{C2}}{X_{C1} + X_{C2}}$ $\quad$ $X_{C_t} = \frac{X_C}{N}$

(two reactances) $\quad$ (equal reactances)

# FORMULAS BLOCK III

## SERIES REACTIVE CIRCUITS

$E_a = I_t Z_t$ $\qquad$ $I_t = \frac{E_a}{Z_t}$ $\qquad$ $Z_t = \frac{E_a}{I_t}$

$$P_{true} = I\,E_R = I^2 R = \frac{{E_R}^2}{R} = P_a \times PF$$

$$P_{apparent} = IE_a = I^2 Z_t = \frac{{E_a}^2}{Z_t} = \frac{P_t}{PF}$$

$$\text{Power factor (PF)} = \frac{P_{true}}{P_{apparent}} = \frac{P_t}{P_a} = \frac{E_R}{E_a} = \frac{R}{Z} = \cos \Theta$$

$$\text{Sine } \Theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{X}{Z} \quad \text{Cosine } \Theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{R}{Z} \quad \text{Tan } \Theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{X}{R}$$

## SERIES RC CIRCUITS

$E_a = \sqrt{{E_R}^2 + {E_C}^2}$ $\qquad$ $Z = \sqrt{R^2 + {X_C}^2}$

## SERIES RL CIRCUITS

$E_a = \sqrt{{E_R}^2 + {E_L}^2}$ $\qquad$ $Z = \sqrt{R^2 + {X_L}^2}$

## SERIES RCL CIRCUITS

$E_a = \sqrt{{E_R}^2 + (E_L - E_C)^2}$ $\qquad$ $Z = \sqrt{R^2 + (X_L - X_C)^2}$

## SERIES RESONANCE

$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{.159}{\sqrt{LC}}$ $\qquad$ Current Half Power Point = $.707\ I_{max}$

Upper half power point = $f_2$ $\qquad$ Bandwidth (BW) = $f_2 - f_1$

Lower half power point = $f_1$ $\qquad$ Bandpass = $f_1$ to $f_2$ = $(f_r - \frac{BW}{2})$ to $(f_r + \frac{BW}{2})$

$Q = \frac{f_r}{BW} = \frac{X_L}{R} = \frac{X_C}{R}$ $\qquad$ $X_L$ or $X_C$ (at resonance) = $\sqrt{\frac{L}{C}}$

## PARALLEL REACTIVE CIRCUITS

$E_a = I_t Z_t$ $\qquad I_t = \frac{E_a}{Z_t}$ $\qquad Z_t = \frac{E_a}{I_t}$

$P_{true} = I_R E_R = I_R^2 R = \frac{E_R^2}{R} = P_a \times PF$

$P_{apparent} = I_t E_a = I_t^2 Z = \frac{E_a^2}{Z} = \frac{P_t}{PF}$

Power factor (PF) $= \frac{P_t}{P_a} = \frac{I_R}{I_t} = \text{Cos } \theta$

## PARALLEL RC, RL, AND RCL CIRCUITS

$I_t = \sqrt{I_R^2 + I_C^2}$ $\qquad I_t = \sqrt{I_R^2 + I_L^2}$ $\qquad I_t = \sqrt{I_R^2 + (I_L - I_C)^2}$

## PARALLEL RESONANCE

$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{.159}{\sqrt{LC}}$

Voltage half power point = .707 $E_{max}$

Impedance half power point = .707 $Z_{max}$

Bandwidth (BW) $= f_2 - f_1$

$f_1$ = Lower half power point

$BW = \frac{f_r}{Q_{tank}} = \frac{f_r \times X_L}{R_{parallel}}$

$f_2$ = Upper half power point

$Q = \frac{R}{X_L}$ (for parallel resistance) $\qquad Q = \frac{f_r}{BW} = \frac{X_L}{R_L} = \frac{I_{tank}}{I_{line}}$ (for series resistance)

$I_{tank} = \frac{E_{tank}}{X_L} = \frac{E_{tank}}{X_C}$ (at resonance) $\qquad I_{line} = I_t$

## TIME CONSTANTS

$TC = R \times C$ $\qquad$ TC in seconds, R in ohms, C in farads, and L in heneries

$TC = \frac{L}{R}$ $\qquad \#TC = \frac{t}{TC}$ $\qquad \#TC = \frac{R \times t}{L}$ $\qquad \#TC = \frac{t}{R \times C}$

$t = \#TC \times \frac{L}{R}$ $\qquad t = \#TC \times R \times C$ $\qquad$ % of charge $= \frac{E_C}{E_a} \times 100$

$R = \frac{t}{\#TC \times C}$ $\qquad C = \frac{t}{\#TC \times R}$ $\qquad L = \frac{R \times t}{\#TC}$ $\qquad R = \frac{\#TC \times L}{t}$

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Electronic Principles (Modular Self-Paced)

# SAFETY PRECAUTIONS AND FIRST AID FOR ELECTRONICS ENVIRONMENTS

1 July 1974

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# SAFETY PRECAUTIONS AND FIRST AID FOR ELECTRONIC ENVIRONMENTS

## SAFETY

Safety is the responsibility of every individual in the Air Force. This includes personal safety and the safety of others. The supervisor is responsible for instructing personnel in the safety practices applicable to the operations which are performed in your maintenance unit. Likewise, it is your responsibility as a repairman of electronic equipment to understand and observe the safety standards and regulations established for your unit.

The installation, maintenance, and operation of electronic equipment has several elements of danger. Carelessness on your part can result in serious injury or death as a result of electrical shock, falls, burns, flying objects, etc. The chief causes of accidents are unsafe conditions and unsafe acts. It is your responsibility to identify and eliminate unsafe conditions which cause accidents. In practically every instance, unsafe conditions are identifiable and can be eliminated by exercising foresight and common sense. Unsafe acts can be reduced if each repairman is informed concerning safety matters and maintains a continuous awareness of hazards and safety procedures.

The following list indicates the common causes of accidents which occur around maintenance facilities. Note that the human element of carelessness is present in every case.

1. Operating equipment without proper authority.
2. Working without sufficient experience.
3. Not following safety precautions.
4. Not using safety devices.
5. Operating unsafe equipment.
6. Careless housekeeping.
7. Working at unsafe speeds.
8. Indulging in horseplay.
9. Assuming unsafe body-position while working.
10. Operating moving equipment without a proper safety guard.
11. Failing to warm individuals of possible dangers.
12. Fatigue

## SAFETY PRECAUTIONS IN MAINTENANCE PRACTICES

Most of the hazards which will confront you as a repairman of electronic equipment will be associated with careless maintenance practices. Precautions or preventive measures to be observed in relation to such accidents are either listed or discussed in the following text.

Most injuries incurred while working around the shop will not require immediate first aid on your part; that is, there will be time to call some professionally qualified person to administer first aid. However, you should familiarize yourself with first aid methods since a doctor or qualified first aid technician may not be available for some time. AF Pamphlet 35-5-3, First Aid for Airmen, is an excellent reference for first aid familiarization.

There are two types of injuries, resulting from an accident, which may require you to administer first aid immediately to save a life. In the case of severe electrical shock, the victim's system may be paralyzed; in such cases immediate artificial respiration is necessary to save the victim's life. Since you will be working with tools and equipment, it is always possible that you or someone else may receive a wound from which there is excessive or dangerous bleeding. In such a case, your knowledge of how to control the flow of blood may mean the difference betwee life and death for yourself or a fellow worker. Each of these first aid measures is discussed in detail later in this chapter. Study and practice the procedures until they are natural to you.

### Safety with Electrically Powered Tools

Hazards associated with the use of electrically powered tools are electrical shock, burns, cuts, bruises, falls, strains, sprains, particles in the eye, and explosions. Safe practice in the use of electrically powered tools will reduce or eliminate such accidents.

Listed below are some general safety precautions to be observed when working with electrically powered tools:

1. See that all cables of power tools are located so that they will not constitute a tripping hazard.

2. See that all electrically powered tools are properly grounded.

3. See that powered tools have all dangerous moving parts guarded.

4. Wear goggles when doing work where particles may strike the eye.

5. Check to see that electrical conductors are completely insulated.

6. Replace defective cords and plugs immediately.

7. Do not attempt to operate a power tool until you are trained, or under your trainer's supervision.

8. After operation, disconnect the electrical power cord.

9. If you are a supervisor, instruct all personnel in the correct use of power tools and inform them of the hazards present and safety practices to be observed.

### Safety With Soldering Irons

The following list of safety precautions should be observed when working with soldering irons:

1. Always assume a soldering iron to be hot.

2. Never rest an iron anywhere but on a metal rack provided for that purpose.

3. Never use excessive solder because dripping solder may cause burns. Should excess solder collect on the iron, remove with a rag. Do not swing the iron to remove solder.

4. See that the cord and plug on the iron that you intend to use are in good condition.

5. To prevent burns, hold small soldering jobs with pliers or clamps.

6. When cleaning an iron, place the cleaning rag on a suitable surface and wipe the iron across it. Do not hold the rag in the hand.

### Safety With A Blow Torch

Observe the following precautions when working with a blow torch:

1. Do not use a blow torch in an unventilated location or in the vicinity of gasoline or other flammable liquids or substances.

2. Set the blow torch in a secure place before preparing to light it.

3. Do not light a blow torch with gasoline spillage over it.

4. Do not light a blow torch when gasoline is burning in the bowl below the vaporizing unit.

### General Maintenance Practice Precautions

The following is a listing of common sense safety precautions concerning general items. Fix them in your mind and observe them.

1. Do not wear metal identification bracelets, wrist watches, or rings while working with electrical equipment.

2. Keep your clothing, hands, and feet dry if at all possible.

3. Pull the fuses, open the circuit breakers, or disconnect the circuits from their source of power to protect yourself, the test euipment, and the equipment under test.

4. Do not use your bare hands to remove hot tubes from their sockets. You may burn your hands and drop the tube. Use asbestos gloves or a tube puller for removing hot tubes.

5. Do not troubleshoot a circuit with the primary power applied, unless absolutely necessary.

6. If it becomes necessary to work on equipment with the power applied, keep one hand free at all times (behind you or in your pocket).

7. Be aware of charged capacitors when making voltage checks and other circuit checks.

8. Be certain that there is no power applied to a circuit when making a continuity or resistance check. (The meter will be damaged.)

9. Use the correct tool (screwdriver, alignment tool, etc.) for doing the job.

10. Carefully inspect the insulation on the test leads to your test equipment. The slightest break in the insulation may be dangerous.

11. Turn off the power before connecting alligator clips to any circuit.

12. Never use toxic or flammable solvents for cleaning purposes.

13. DO NOT TAKE ANYTHING FOR GRANTED when working with inexperienced help. Check every operation before they perform it.

High-Voltage Safety Precautions

Body resistance to electrical current varies between 100,000 and 600,000 ohms for dry skin to 1,000 ohms for wet skin. The internal resistance of the body, hand to foot, is about 400 to 600 ohms; from ear to ear it is about 100 ohms. Even though the human skin has high resistance and therefore acts as a partial protector against electrical shock, it may be mortally dangerous to come in bodily contact with an exposed power lead or other point of potential or electronic equipment.

Suppose 115 volts were applied to the perspiring skin of a worker who is standing on a good electrical ground. Assuming a total resistance of 1,500 ohms (skin, body, and ground contacts), the current through the worker's body would be about .077 ampere or 77 milliamperes. Though this amount of current may or may not be fatal, there will always be pain, sever muscular contractions, and breathing difficulties. When we think of electrocution, we are inclined to think in terms of high voltages, but a point always to remember is that MORE PEOPLE ARE KILLED BY 115 VOLTS THAN ANY OTHER VALUE.

The following list indicates the safety precautions to be practiced when working with equipment where high voltages are present. Failure to observe these precautions could result in death.

1. Never trust a switch.

2. Do not rely on safety devices.

3. Inform the remote station as to the circuit on which you will be working.

4. Place a DANGER sign "DANGER - DO NOT USE OR OPERATE" or a similar warning note at the switch or circuit breaker of the circuit on which you will be working.

5. Turn the power switch to the OFF position.

6. Remove all fuses from circuits where switches might be closed accidentally or unintentionally.

7. Always be aware of the nearness of high-voltage lines or circuits to prevent accidental touching.

8. Do not work with high-voltage equipment by yourself; have another person (safety observer), qualified in first aid for electrical shock, present at all times.

9. Do not rely upon the insulation as complete protection against electrical shock.

10. Keep your feet clear of objects on the floor.

11. Stand on a good rubber mat. (Not all so-called "rubber mats" are good insulators).

12. Use rubber gloves when applicable. Make certain rubber gloves are in good condition and tested for holes and insulation breakdown.

13. Use a shorting stick to discharge all high-voltage capacitors.

14. Do not change electron tubes or make adjustments inside equipment when the high-voltage supply is on.

15. Make certain that the high-voltage plate circuits are turned off before performing preventive maintenance on the equipment.

16. Make certain that the equipment is properly grounded. Ground all test equipment to the equipment under test.

### Rescue of Shock Victims

The victim of electrical shock is dependent upon you to give prompt first aid. Unless you want to become a victim yourself, observe these precautions.

1. Shut off high voltage at once.

2. If the high voltage cannot be turned off without delay, free the victim from the live conductor. REMEMBER:

a. Protect yourself with dry insulating material.

b. Use a dry board, your belt, dry clothing or other non-conductor material to free the victim. When possible PUSH - DO NOT PULL the victim free of the high-voltage source.

c. Use an ax if necessary to cut the high-voltage wire.

d. DO NOT touch the victim with your bare hands until the high-voltage circuit is broken.

## FIRST AID

At the present time you are limited as to the amount of first aid that you are allowed to give to injured personnel. Your responsibility, however, is the effective accomplishment of the following three steps:

1. Call for a medical officer and pulmotor, if possible, but DO NOT DELAY ADMINISTERING FIRST AID WHILE WAITING FOR EITHER.

2. Stop all serious bleeding quickly.

3. If breathing has stopped, apply artificial respiration immediately.

### Control of Bleeding

Uncontrolled bleeding may cause or increase shock and finally result in death. Stop any severe bleeding immediately. To stop bleeding, first apply pressure to the wound with a dressing, or, if necessary, with some substitute material such as a clean shirt or handkerchief. Be sure to use clean materials. Place the dressing or cloth against the wound and apply firm pressure. See figure 1-1. Continue the pressure as long as needed. Use an additional dressing to cover the wound, if necessary. Wrap the tails of the dressing around the wounded part and tie the ends to hold the dressing firmly against the wound.

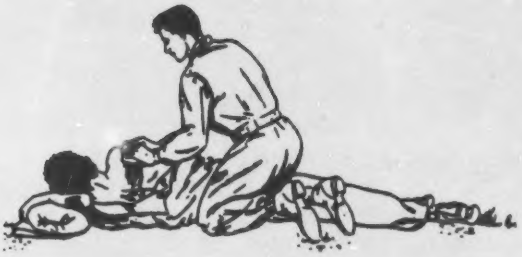

Figure 1-1. Control of Bleeding

If the wound is on an arm or leg and if the bleeding continues, place the patient in a prone position with the wounded arm or leg raised. In this position the blood does not flow into the wounded limb so fast, thus bleeding from the wound is slowed. The bleeding is slowed, not stopped, by raising the arm or leg, so you still have to use the dressing and pressure.

DO NOT raise the limb if you think the bone is broken. Moving a broken arm or leg is dangerous, since it may result in further injury to the patient and may increase shock.

A TOURNIQUET SHOULD BE USED ONLY FOR SEVERE, LIFE-THREATENING HEMMORRHAGE THAT CANNOT BE CONTROLLED BY OTHER MEANS. Its application may cause tissue injury; it may completely shut off the entire blood supply to the part below, and the pressure device itself often cuts into or injures the skin. It is only rarely required. Tourniquets should be used only when severe bleeding involves an extremity in which the large arteries are severed, or in cases of partial or complete severance of a body part. These are the only instances where application of a tourniquet may be justified. If it is necessary to use a tourniquet, follow the procedure illustrated in figure 1-2.

A tourniquet should be tightened only enough to stop arterial bleeding (gushing of blood from the wound). Veins usually continue to bleed until the limb is drained of blood already present in it; thus, in such an instance, bleeding is not reduced by further tightening of the tourniquet.

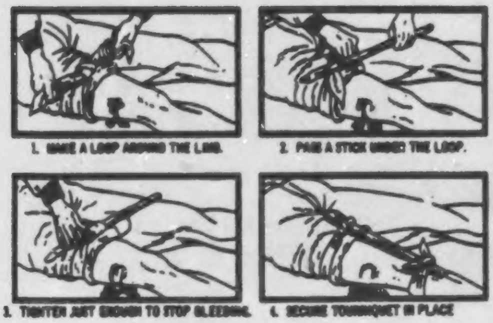
1. MAKE A LOOP AROUND THE LIMB.
2. PASS A STICK UNDER THE LOOP.
3. TIGHTEN JUST ENOUGH TO STOP BLEEDING.
4. SECURE TOURNIQUET IN PLACE

Figure 1-2. Application of a Tourniquet

Always place the tourniquet between the wound and the heart, in most cases as low as possible just above the wound. However, in the case of bleeding below the knee or elbow, a tourniquet should be placed just above these joints. When possible, project the skin by putting a tourniquet over the smooth sleeve or trouser leg.

THE PATIENT SHOULD BE SEEN BY A MEDICAL OFFICER AS SOON AS POSSIBLE once the tourniquet is applied. The tourniquet should not be loosened by anyone except a medical officer prepared both to stop the bleeding by other means and to replace the blood volume by transfusion. Repeated loosening of the tourniquet by inexperienced personnel is extremely dangerous because the life of the patient is endangered through further loss of blood.

If conditions permit you to stay with the wounded person, inspect the tourniquet frequently to see if it has slipped or if there is any sign of further bleeding. If necessary, replace the tourniquet to its proper position. If further bleeding occurs, further tightening of the tourniquet may be necessary.

In extremely cold weather, arms or legs to which tourniquets have been applied are subject to cold injury; therefore, such extremities should be protected from the cold.

Often you can reduce or stop bleeding by applying hand or finger pressure at various points on a patient's body. The locations of these points are shown in figure 1-3. If help is available, have the person use an appropriate pressure point while you apply a tourniquet. The pressure points in the groin and neck are particularly important. If the wound is too high on the leg for a tourniquet to be applied, the pressure points in the groin can be used. A neck pressure point should be used when the casualty has a profusely bleeding scalp wound; however, use the neck pressure point only as a last resort--when other methods of stopping bleeding have failed. Figure 1-3 shows a means of applying pressure with the hand. This method may also be used on the head and neck pressure points, using the index and middle fingers. The heel of the hand is used to apply pressure to the groin.

CAUTION. Do not apply pressure to both neck points at the same time. To do so would cut off the blood supply to the brain, causing unconsciousness and then death.

### Artificial Respiration

Immediate action must be taken in cases of drowning and electric shock. Seconds count. They can mean the difference between death and recovery. You should thoroughly acquaint yourself with the first-aid-measures for such emergencies. Artificial respiration is the fundamental first-aid-measure for either of these emergencies; therefore, the procedures for giving artificial respiration are covered in this chapter.

Artificial respiration is not restricted to the treatment of victims of drowning and electric shock. ARTIFICIAL RESPIRATION IS USED TO START BREATHING IN PERSONS WHOSE BREATHING HAS STOPPED. This may also occur in carbon monoxide or other gas poisoning, in persons who have been in large fires, exposed to severe blasts, and in other cases of unconsciousness. When breathing is inadequate the victim will always be pale or more blue than usual except in carbon monoxide poisoning in which case the symptoms may be giddiness, weakness, headache, vomiting, and unconsciousness.

The most important thing to remember in giving artificial respiration is to BEGIN IMMEDIATELY. Don't waste time moving the victim to the ideal location; don't wait for a mechanical resuscitator, which is to be used ONLY by a QUALIFIED PERSON. Start at once.

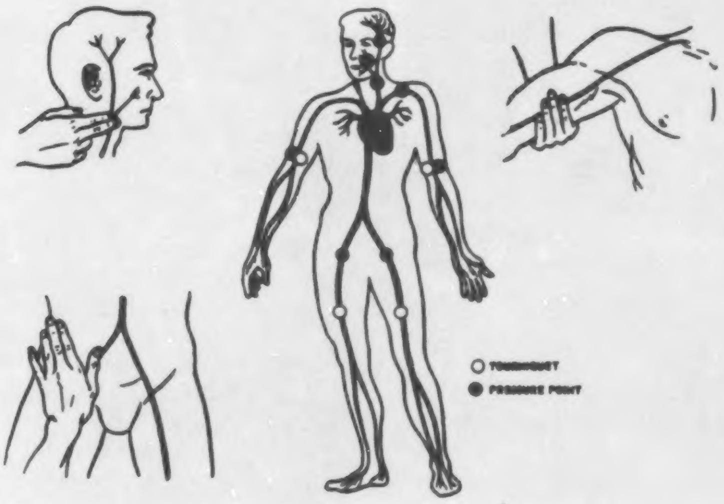

Figure 1-3. Pressure Points and Application

An important consideration in any method of artificial respiration is that the AIR PASSAGEWAY BE OPEN. If there is an obstruction, air cannot enter the lungs regardless of the method used. The air passageway of the unconscious victim is usually blocked to some degree. There are three main causes for obstruction. The first is liquid, false teeth, or other foreign matter in the mouth or throat. The second is relaxation of the jaw. The tongue is attached to the jaw so that it falls backward and blocks the throat (called "swallowing the tongue"). The third is the position of the neck. When the neck is bent forward so that the chin is down close to the chest, there is a tendency for the throat to become "kinked" and block the passage of air. The air passageway can be kept open by placing the head in the position of an individual looking upwards.

You may have learned the old prone pressure method of administering artificial respiration, or the more recent back-pressure-arm-lift (B-P-A-L) method, or the back-pressure-hip-lift (B-P-H-L) method. In the use of these methods, the victim must be lying on his stomach. There is also a new method where the victim is placed on his back. This method is known as the mouth-to-mouth or exhaled-air method.

MOUTH-TO-MOUTH METHOD (EXHALED-AIR METHOD). It has been proven that the mouth-to-mouth method of artificial respiration is the most effective method. It is simpler to use and saves more lives. Do not waste time trying old methods, or worrying about getting infected. The possibility of infection is remote. YOU HAVE A LIFE TO SAVE.

In this method, you breathe air into the victim's lungs with your own mouth. Since you consume only part of the oxygen out of the air which you inhale, the air you breathe into the victim's lungs contains enough oxygen to revive him.

You'll find that you need to breathe slightly deeper and faster than usual in order to get enough air for yourself, but don't worry about this point. Under certain conditions, which will be explained later, the mouth-to-mouth method of artificial respiration cannot be used. The step-by-step procedure for administering mouth-to-mouth artificial respiration follows:

STEP 1. TURN THE VICTIM ON HIS BACK.

STEP 2. CLEAN THE MOUTH, NOSE, AND THROAT. If the mouth, nose and throat appear clean, start exhaled-air artificial respiration immediately. If foreign matter such as vomit or mucus is visible in the mouth, nose, and throat, wipe it away quickly with a cloth or by passing the index and middle fingers through the throat in a sweeping motion. (See figure 1-4.)

STEP 3. PLACE THE VICTIM'S HEAD IN THE "SWORD-SWALLOWING POSITION." The head must be placed as far back as possible so that the front of the neck is stretched.

STEP 4: HOLD THE LOWER JAW UP (See figure 1-5). Approach the victim's head preferably from his left side. Insert the thumb of your left hand between the victim's teeth at the midline. Pull the lower jaw forcefully outward so that the lower teeth are further forward than the upper teeth. Hold the jaw in this position as long as the victim is unconscious. A piece of cloth may be wrapped around the thumb to prevent injury by the victim's teeth.

In the case of young children (under age 3) or in a victim who has tight jaws grasp the angles of the lower jaw below the ear lobes, with both of your hands, one on each side of the victim's head (see figure 1-7). Lift the lower jaw forcefully outward so that the lower teeth are further forward than the upper teeth. To open the lips, pull the lower lip down with the thumbs while forcefully holding the lower jaw forward. Hold the jaw in this position as long as the victim is unconscious.

STEP 5. CLOSE THE VICTIM'S NOSE. Close the victim's nose by compressing it between the thumb and forefinger of the right hand as shown in figure 1-6. In the case of YOUNG CHILDREN (UNDER AGE 3) or in a victim who has tight jaws, block the victim's nose to prevent air leakage by pressing your right cheek against the nasal openings as shown in figure 1-8. (The hands will be occupied elsewhere).

STEP 6. BLOW AIR INTO THE VICTIM'S LUNGS. Take a deep breath and cover the victim's open mouth with your open mouth making contact airtight. In the case of a baby, the rescuer's mouth can cover both the mouth and nose with an airtight contact. Blow rapidly until the chest rises. If the chest does not rise when you blow in, improve the position of the victim's air passageway, and blow more forcefully. Blow FORCEFULLY into ADULTS and GENTLY into CHILDREN.

STEP 7. LET AIR OUT OF VICTIM'S LUNGS. After chest rises, quickly separate lip contact with the victim, and allow the victim to exhale by himself.

Repeat Steps 6 and 7 at a rate of 12 to 20 times per minute. Continue rhythmically without interruption until the victim starts breathing or is pronounced dead. A smooth rhythm is desirable, but split-second timing is not essential.

Several devices consisting of a short tube with a mask at one end to cover the victim's face have been developed to increase efficiency and provide sanitation. One, the "venti-breather," (shown in figure 1-9) has a valve to control inhalation and exhalation through slots in the tube. The rescuer breathes in one end of the tube. A mask at the other end covers the victim's nose and mouth, permitting air to be blown through the nose in case the lips are clamped shut. There is no need to hold the nose closed. Venti-breather does away with step 5 above and changes steps 6 and 7 since lip contact is not required. All other steps are as described above. Clean victim's mouth and throat with fingers. Hold the jaw and mask as shown in figure 1-10. (In some cases the thumb and index finger can be used to hold the mask to the face thus freeing the other hand.) Be sure the mask is airtight to the face; that the head is in the sword-swallowing position; that the jaw is pulled forward; and watch to see that the victim's chest rises and falls. If it doesn't, try using two hands to hold the victim's jaw up, one on each side.

GENERAL PRECAUTIONS. After exhaled-air artificial respiration has been performed for a period of time, the VICTIM'S ABDOMEN MAY BULGE. This is due to air which is blown into the victim's stomach. Air inflation of the stomach rarely occurs when the correct technique is applied. It does occur if the air passageway is blocked by improper support of the head and lower jaw or if the blowing is too forceful.

Air inflation of the stomach is not dangerous, but inflation of the lungs is easier when the stomach is empty. If the rescuer sees the abdomen bulging, he should interrupt blowing for a few seconds and press with his hand on the upper abdomen causing the air to be "burped". Since this maneuver may cause the victim to "vomit" also, the rescuer must be ready to roll the victim's head to the side and clean the throat at once.

The drowning victim may or may not have water in the lungs. Water cannot be removed from the lungs satisfactorily by any means. Exhaled-air artificial respiration is effective, even with water in the lungs.

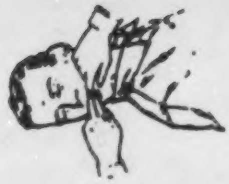

Figure 1-4

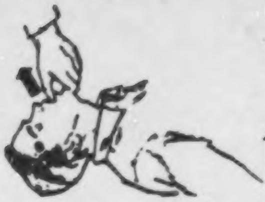

Figure 1-5

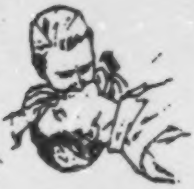

Figure 1-6

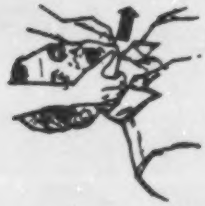

Figure 1-7

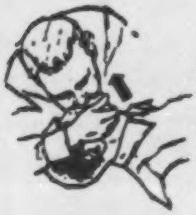

Figure 1-8

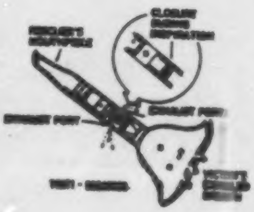

Figure 1-9

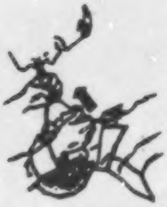

Figure 1-10

The drowning victim usually swallows large amounts of water. When the rescuer performs the first few breaths of exhaled-air artificial respiration, the water may be pushed into the victim's throat due to pressure transmitted through the diaphragm by the extending lungs. The rescuer must be alert to this possibility and roll the victim's head to the side immediately so that the water and other materials drain out. Exhaled-air artificial respiration should be resumed as quickly as possible.

If the VICTIM APPEARS TO BE BREATHING TO SOME DEGREE, keep his air passageway open until he awakens by maintaining the support of his lower jaw. If his tongue or fingernails are blue rather than pink, he is not breathing adequately and requires assistance. The rescuer must perform exhaled-air artificial respiration by breathing air into the victim's lungs each time that the victim himself breathes in. Adjust your timing to assist him. Do not fight his attempt to breathe. Synchronize your efforts with his.

The victim may appear to be breathing because of movement of his chest and abdomen. Actually no air may be moving into his lungs due to complete obstruction of the air passageway from improper positioning of the head and jaw. For this reason, it is most important to determine whether or not there is any movement of air in and out of the mouth and nose by listening closely.

The victim may be BREATHING NOISILY (SNORING) indicating partial obstruction of the air passageway. This may be relieved by holding the victim's head in a sword-swallowing position and the jaw thrust forward.

As soon as the patient starts breathing, or additional help becomes available, see that the patient's clothing is loosened (or if wet, removed) and that he is treated for traumatic shock by lowering head and shoulders, elevating his legs and keeping him warm (see section on Traumatic Shock). Do not, however, interrupt artificial respiration to do this before he starts breathing.

It is extremely important that the rescuer remain at the victim's head during transportation at all times in order to keep the victim's air passageway open by the methods described previously and to start an exhaled-air technique of breathing if the victim ceases to breathe.

Exhaled-air artifical respiration will also work for a person who stops breathing because he has gotten too little oxygen at high altitude. However, it only works if there is enough oxygen in the air you breathe out. There will not be enough oxygen, if you are above 10,000 feet cabin altitude and not getting oxygen through a mask. In this case, it is best to apply a resuscitator. If a reresuscitator is not available, quickly apply to the victim a mask which is attached to an operative oxygen regulator. Switch the regulator on and to 100 percent oxygen and give back-pressure-arm-lift (B-P-A-L) artificial respiration as explained in the following section.

Under any conditions which require you to wear a mask, you cannot give exhaled-air artificial respiration. This will be true during gas attack and under certain conditions of biological and radiological warfare. The older back-pressure-arm-lift (B-P-A-L) or back-pressure-hip-lift (B-P-H-L) method must usually then be used while the victim wears a gas mask. Be sure to watch the mask for vomit and clear mask if needed. If the expiratory valve of your gas mask can be attached to the tube on an artificial respiration mask such as the venti-breather it would then be possible to give exhaled-air artifical respiration.

The B-P-A-L METHOD OF ARTIFICIAL RESPIRATION. When exhaled-air artificial respiration cannot be given, the back-pressure-arm-lift method is preferred over the back-pressure-hip-lift method. Use the B-P-A-L method unless the victim has an injury, such as a broken arm, which makes it necessary to use an alternative method. The step-by-step procedures for administering the B-P-A-L artificial respiration are as follows:

1. Position of the subject: Place the victim in the face down, prone position. Bend his elbows and place the hands one upon the other. Turn his face to one side, placing the cheek upon his hands. Refer to figure 1-11.

2. Position of the operator: Kneel on either the right or left knee at the head of the victim, facing him. Place the knee at the side of the subject's head close to the forearm. Place the opposite foot near the elbow. If it is more comfortable, kneel on both knees, one on either side of the victim's head. Place your hands upon the flat of the victim's back in such a way that the heels of the hands lie just below a line running below the armpits, with the tips of the thumbs just touching; spread the fingers downward and outward. Refer to figure 1-12.

3. Compression phase: Rock forward until the arms are approximately vertical and allow the weight of the upper part of your body to exert slow, steady, even pressure downward upon the hands. This forces air out of the lungs. Your elbows should be kept straight and the pressure exerted almost directly downward on the back. Refer to figure 1-13.

4. Position for expansion phase: Release the pressure, avoiding a final thrust, and commence to rock slowly backward. Place your hands upon the victim's arms just below his elbows. Refer to figure 1-14.

5. Expansion phase: Draw his arms upward and toward you. Apply just enough lift to feel resistance and tension. Do not bend your elbows. As you rock backward the victim's arms will be drawn toward you. Lower the arms to the ground. This completes the full cycle. The arm lift expands the chest, arches the back, and relieves the weight on the chest. Refer to figure 1-15.

**THE CYCLE SHOULD BE REPEATED 12 TIMES PER MINUTE AT A STEADY UNIFORM RATE. THE COMPRESSION AND EXPANSION PHASES SHOULD OCCUPY ABOUT EQUAL TIME: THE RELEASE PERIODS BEING OF MINIMUM DURATION.**

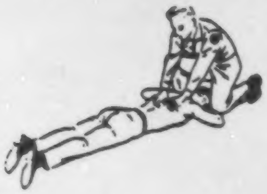

Figure 1-11. Position of Subject

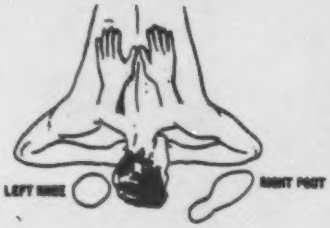

Figure 1-12. Position of Operator

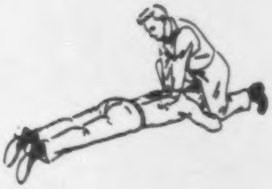

Figure 1-13. Compression Phase

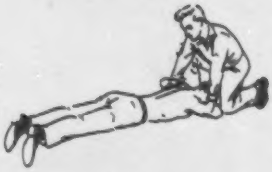

Figure 1-14. Position for Expansion Phase

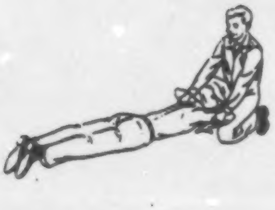

Figure 1-15. Expansion Phase

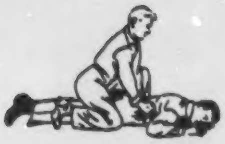

Figure 1-16. Compression (B-P-H-L)

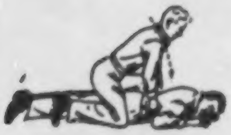

Figure 1-17. Compression (B-P-H-L)

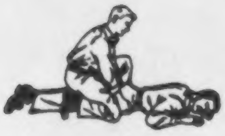

Figure 1-18. Lift Position (B-P-H-L)

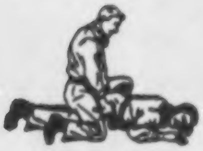

Figure 1-19. Expansion (B-P-H-L)

The B-P-H-L METHOD OF ARTIFICIAL RESPIRATION. Where arm injuries render the back-pressure-arm-lift method impractical, the back-pressure-hip-lift method is prescribed. It is effective, though more tiring to the operator.

1. Place one knee on the gound beside the victim's hip. Straddle him and place the other foot on the ground near the other hip, facing the direction of the victim's head. Refer to figure 1-16.

2. Place your hands on the victim's back just below the shoulder blades with the thumbs about 2 inches apart along the spine. Lean forward with your elbows straight and let the weight of the upper part of your body put a steady, gentle pressure on the victim's back. Refer to figure 1-17. Release the pressure quickly but without any extra push at the release.

3. Place your hands under the victim's hip bones where they touch the ground--NOT UNDER THE WAIST--and lift the hips vertically about 4 to 6 inches. Refer to figure 1-18 and figure 1-19.

4. Gently replace the hips to the ground. DO NOT DROP. Repeat the cycle 10 to 12 times a minute. It is possible to change knees but do not break the regular rhythm of the cycle.

## TRAUMATIC SHOCK

When the human body undergoes great strain due to severe injury, loss of blood, pain, and/or psychic factors, it usually results in a state of condition called traumatic shock or commonly called "shock". This type of shock is a profound and critical condition. Once it has developed, there is little to be accomplished in the absence of qualified medical personnel. Prevention of traumatic shock is therefore very important. Treatment to prevent shock should be started as soon as possible when a victim is found injured, in severe pain, or unconscious due to injury, pain, or psychic factors.

### Symptoms

Symptoms of traumatic shock are listed below:

1. The eyes of the victim have a vacant stare and the pupils are dilated.
2. Breathing is shallow and irregular.
3. The skin is pale, cold and moist.
4. The pulse is weak or absent.

### Treatment

To prevent or treat shock, follow the instructions listed below:

1. Control bleeding and pain.
2. Place victim horizontally, with the head lowered and feet elevated.
3. Do not move the victim more than absolutely necessary.
4. Loosen clothing, belt, tie, top buttons, etc.
5. Keep the patient warm. Wrap in a blanket, coat or similar covering. Protect the body underneath as well as on top.
6. Seek qualified medical aid, but do not leave the patient alone.
7. Stimulants, plain water, either hot or cold, coffee, milk, or tea may be given ONLY AFTER THE PATIENT HAS REGAINED CONSCIOUSNESS and if there will be a delay in obtaining medical care. NEVER GIVE A STIMULANT TO A PATIENT WHO IS UNCONSCIOUS OR PARTLY CONSCIOUS, IF HE IS NAUSEATED, HAS INTERNAL INJURIES, OR PROBABLY FACES AN EARLY OPERATION. If stimulants are given, give only a few sips at first, then in small doses and at such intervals that he does not vomit. Stimulants will not usually be given by the person performing first aid.

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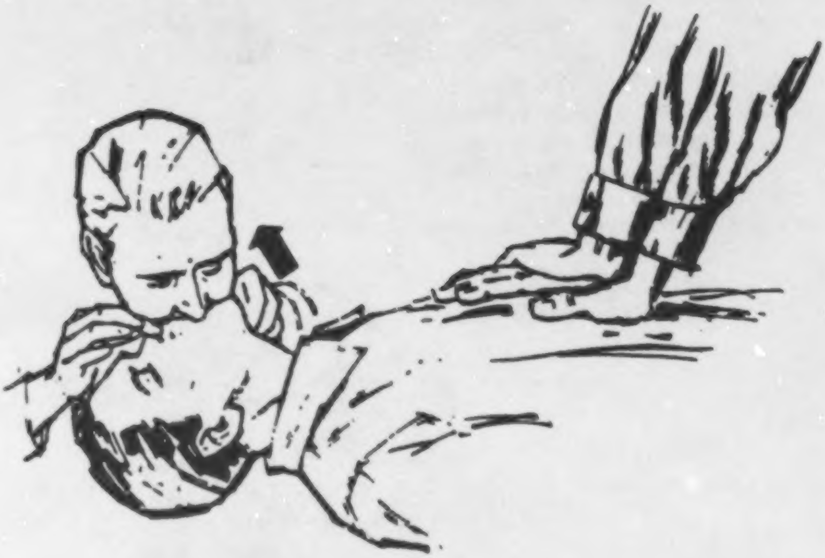
CAUTION. When a victim is NOT breathing, the act of administering artificial respiration is more important than prevention of traumatic shock. Treatment for preventing shock can be given by someone else as artifical respiration is started or as it is given. It is very important to start artificial respiration immediately when breathing stops.

## CARDIAC ARREST
## CLOSED HEART MASSAGE

1. This procedure requires the services of two persons.

IN THE EVENT OF CARDIAC ARREST (Absence of pulse), CALL A PHYSICIAN IMMEDIATELY, PLACE THE PATIENT ON A HARD, FLAT SURFACE AND APPLY ARTIFICAL RESPIRATION AND THE PROCEDURE SHOWN BELOW FOR CLOSED HEART MASSAGE.



Procedure for Person #1:

1. Place the heel of one hand on the lower chest (see illustration) with the second hand on the first.

2. Rhythmically compress the heart by exerting your approximate body weight on the lower chest.

3. Maintain pressure for 1/2 second.

4. Release pressure.

5. Repeat at a rate of 60-80 per minute.

6. Chest should not move more than 3-5 centimeters when pressure is applied.

7. DO NOT exert pressure on the rib cage.

Procedure for Person #2

1. Simultaneously apply artificial respiration.

2. Use Mouth-to-Mouth, Mouth-to-Nose, or other rapidly available methods.

3. Apply at a rate of 12-20 per minute.

4. Feel for pulse and observe the patient's pupils. If circulation is adequate, a pulse must be present and the pupils will constrict. Pupils will dilate with inadequate circulation.

## ACCIDENT REPORTING

Local directives (Keesler Center Supplement 1 to AFR 127-1) require that ANY and ALL ground accidents be reported to the squadron or unit ground safety representative and to the Center Ground Safety Office. If an accident is classified as "reportable", then AF Form 711, "USAF Accident/Incident Report" and 711A "Ground Accident Report" must be accomplished and forwarded to the Ground Safety Officer. AF Manual 127-2, "USAF Accident/Incident Reporting", defines reportable ground accidents and gives step-by-step guidance in filling out the required forms. The basic regulation to be used for all accident reporting is AF Regulation 127-4 on "Safety".

## FIRES

Fires not only cause a tremendous monetary loss to the government, but also result in severe injuries to many airmen and in some cases loss of life. In a Communications-Electronics facility there is always the possibility of a serious fire starting by a short or overload, but they are more frequently caused by carelessness or failure to comply with safety regulations.

We all know that the best way to fight a fire is to prevent it from ever starting. However, all personnel should know how to put out a fire if one should start. This section covers fire prevention, the four classes of fires, and the use of fire extinguishers. Your knowing this information might some day save your life, a building or valuable Air Force equipment.

### Fire Prevention

You should always be alert for any fire hazards that may exist within your section or organization. Fire hazards should be eliminated as quickly as possible. If you can not eliminate a particular fire hazard, report it to your immediate supervisor or Ground Safety Officer.

A fire that starts in electrical equipment can usually be stopped by merely turning off the AC power supply to the equipment. Since electrical equipment is largely constructed of metal, wiring, and small electrical components, the only fuel to feed the fire would be insulation on the wiring or electrical components. In other words, a large fire in electrical equipment is not common. The large fire is usually caused by the overheating of main power lines supplying the electronics equipment. The overheating of the power lines will ignite the building structure materials or flammable materials nearby, and then the large fire starts.

Fires are caused by many other contributing factors. To prevent fires you should have a fire safety program established and periodically inspect your shop or facility to eliminate fire hazards that do exist. Listed below are some important items to check for in the prevention of fires. This list is not considered complete and inspections should not be limited to these items. Your local conditions will determine the type of fire hazards that may exist within your organization.

ELECTRICAL EQUIPMENT. Check all electrical equipment for the following:

1. Poor grounding system.
2. Improper size fuses. Fuses should have the ampere and voltage rating specified in the applicable technical order for the equipment.
3. Fuse boxes not marked with the proper size fuse to be installed.
4. Defective switches and relays.
5. Worn or frayed AC power cords and internal wiring.
6. Broken power plugs and sockets.
7. Dirty, oily, electric motors or generators.
8. Dusty or dirty electronics equipment in general.

FUEL AND PAINT STORAGE AREA. Check the fuel and main storage area for the following:

1. Fuel or paint containers not marked indicating their proper contents.

2. "NO SMOKING" signs not posted.

3. Storage building for fuel and paint located too close to the other facility buildings.

4. Fire control equipment not available for use in the storage area.

5. Fuel or paint spillage within the storage area.

6. Containers not covered or sealed properly.

7. Other materials such as wood, rags or paper being stored in the building.

FIRE CONTROL EQUIPMENT. Check all fire control equipment for the following:

1. Inadequate type and number of fire extinguishers.

2. Fire extinguishers not installed properly or blocked by obstructions.

3. Fire extinguishers not inspected and recharged at proper intervals.

4. Improper use of fire buckets and sand pails. (Sometimes used for cigarette butts and paper).

5. Fire extinguisher seals broken.

6. Fire extinguisher hoses stopped up, or otherwise defective.

BUILDING HOUSEKEEPING. Check the building in general for the following:

1. Trash and foreign materials in the area.

2. Flammable or self-heating materials in unauthorized containers or storage closets.

3. Dead grass or leaves around the buildings and yards.

4. Flammable materials stored in the attic area of building.

5. Unauthorized waste baskets or containers being used. (Should be metal.)

6. Clean and dirty rags being stored in improper containers. (Should be metal and covered.)

7. Designated non-smoking areas not posted with "NO SMOKING" signs.

8. Insufficient ash trays or disposal cans provided for smokers.

9. Fire evacuation plans not posted for safe evacuation of building.

10. Emergency fire reporting procedures not posted, such as phone numbers and building numbers.

HEATING FACILITIES. Check the heating unit area for the following:

1. Insufficient clearance to combustible surroundings, or insufficient insulation and ventilation for heating unit.

2. Heating unit dirty or dusty.

3. Heating facility room area dirty and used for unauthorized storage.

4. Fuel not stored or handled properly.

5. Leaking fuel line in system.

EMERGENCY POWER FACILITY. Check the emergency power unit facility for the following deficiencies:

1. "NO SMOKING" signs not posted.

2. Fuel lines to power units leaking.

3. Grease and oil containers not properly marked and covered.

4. Grease and oil on the floors.

5. Clean and dirty rags stored in improper containers.

6. Improper grounding system for generator units.

7. Main fuse boxes not marked indicating proper size of fuses to use.

8. Improper size fuses being used.

9. Switch boxes not marked properly indicating their control.

10. Drip pans not installed under power units to prevent flammable liquids from spreading on the power building floor.

11. Drip pans are not cleaned as required.

12. Exhaust pipe for power unit engine not insulated properly from building structure.

13. AC wiring from generators not installed according to good installation practices. Look for improper size wire, connectors, under-rated switches, and worn wiring.

## Classes of Fires

Before classifying fires, let us find out what makes a fire burn. To produce a fire, three things must be present at the same time: fuel, heat, and oxygen. If any one of the three is removed, the fire will be extinguished. Fire extinguishers normally remove the heat (cooling effect) or remove the oxygen (smothering effect).

Fires are placed into four classifications to aid in the selection of the proper fire extinguisher.

CLASS A. Burning wood, paper, and rags are examples. The cooling effect of water is often used for these fires. See figure 1-20.

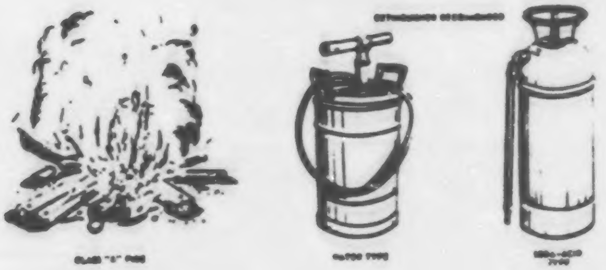


Figure 1-20. Rubbish Fire and Recommended Extinguishers

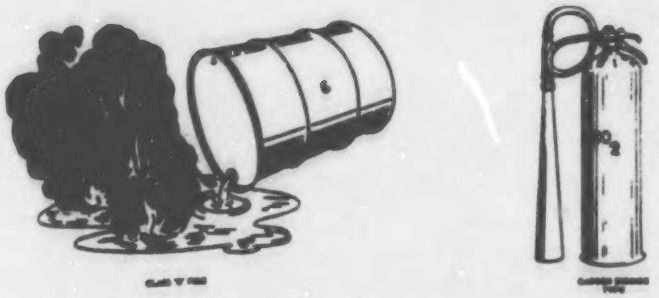


Figure 1-21. Oil Fires and Recommended Extinguisher

CLASS B. Burning gasoline, oil, solvents, and grease are examples. Water cannot be used for these fires. Water would only spread the fire. The smothering effect is used to eliminate oxygen to extinguish this type of fire. See figure 1-21.

CLASS C. Electrical fires are typical of this class. Water must not be used. The extinguishing agent must be a nonconductor of electricity. The smothering effect is normally used to extinguish this type of fire. See figure 1-22.

CLASS D. Burning metals such as magnesium, zinc, sodium, and titanium are examples. Dry-powder extinguishers are used for this class. The smothering effect is used to extinguish this type of fire.

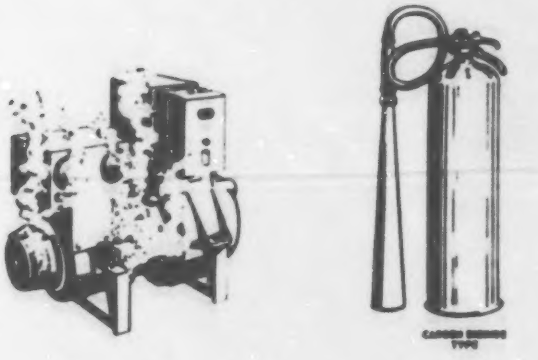


Figure 1-22. Electrical Fire and Recommended Extinguisher

Fire Control

Know your fire extinguishers, where they are located, which one to use, and how to use them. The following types are usually available in the housing or maintenance areas.

1. WATER. Basically tap water. It is used for class A fires. It uses the cooling effect. It is not to be used on electrical fires.

2. SODA-ACID. Sodium bicarbonate solution. Class A fires. Uses cooling effect. Do not use on electrical fires.

3. $CO_2$. CARBON DIOXIDE GAS. Class B and C fires. Uses smothering effect. Commonly used on gasoline, oil, grease, and electrical fires.

4. DRY CHEMICAL. May use sodium bicarbonate or potassium bicarbonate powder. Class B and C fires. Uses smothering effect.

5. DRY POWDER. A special compound of sodium chloride or graphite materials. Used for class D fires. May be applied from extinguisher or applied with a shovel to smother the burning metal.

Your local fire department will determine the proper types of fire extinguishers for your facility or shop. It is your responsibility to know how to use these extinguishers.

The operating instructions for extinguishers are printed on the extinguisher. Learn how to use the extinguisher beforehand. Figure 1-23 shows how to extinguish a typical fire. Direct the agent to the base of the flame.

Be sure to notify the fire department if an extinguisher is used so they can be sure the fire is extinguished and can recharge or replace the extinguisher. Do not use a fire extinguisher for anything except to control a fire.

## TOXIC FUMES AND GASES

Toxic fumes are poisonous vapors or gases generated from a liquid or solid form. A gas is an air-like fluid without a definite limit or form.

Gases and vapors are classified according to their physiological effects. The main groups of gases and vapors are discussed in the following paragraphs.

### Asphyxiants

Simple asphyxiants are gases or vapors which cause a loss of consciousness as a result of too little oxygen and too much carbon dioxide in the blood. This comes as a result of the gases or vapors replacing oxygen in air. Some examples of such gases are methane, carbon dioxide, carbon monoxide, and hydrogen, which replace oxygen in the air.

Methane is a colorless, odorless, inflammable gas and is present in natural gas. It is used as a fuel for heating and illumination. A repairman should pay strict attention to all warning signs, and use the correct procedure for lighting ovens, heaters, stoves, or any device using methane for fuel or lighting.

Carbon dioxide is a colorless, odorless gas somewhat heavier than air. It passes out of the lungs in respiration and controls rate of breathing. As little as 10% can cause death. Oxygen should be sufficient to replace the carbon dioxide at all times. Proper ventilation while working in aircraft and closed shops is a protection against carbon dioxide.

Carbon monoxide is a colorless, odorless, poisonous gas. It is formed when a fire burns with an insufficient supply of air. It is a chemical asphyxiant which combines with the hemoglobin in the blood and prevents oxygen from reaching the body tissues. Carbon monoxide is deadly. Symptoms include dizziness, headaches, nausea, redness of skin, coma, and difficult breathing.

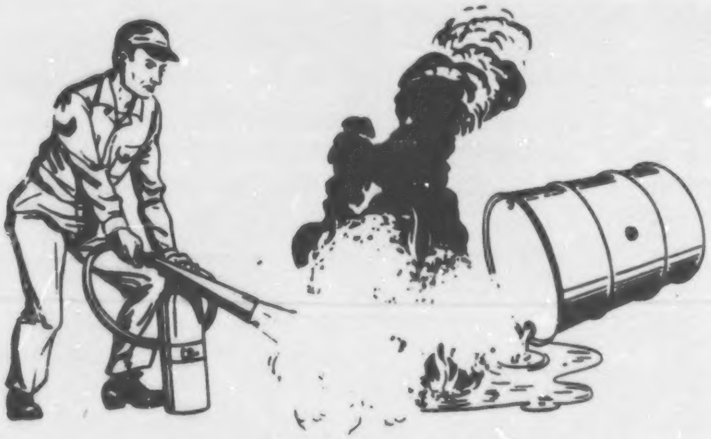


Figure 1-23. Direct Agent to Base of Flame

Hydrogen is a colorless, odorless gaseous chemical element. It is the lightest of all chemical elements and is explosive and inflammable. Repairman should be aware of hydrogen gases in storage battery rooms and aircraft battery compartments. No smoking and constant temperature are precationary measures.

Irritants

Irritant gases and vapors cause irritation or inflammation of the body internally or externally. These gases and vapors cause internal complications, such as lung infection and infection of the vein that conveys blood from the lungs to the heart. The external complications are skin irritations.

Some of the most common types of irritant gases and vapors are produced by ammonia, chlorine, and hydrochloric acid.

Ammonia causes irritation of the eyes and respiratory passages, coughing, and burning of the skin. Repairman may encounter ammonia while working on large air-conditioner units and large refrigeration units and using cleaning substances which contain ammonia. Open air ventilation is the best safety precaution.

Chlorine is a heavy, greenish-yellow poisonous gas with a suffocating odor. It is soluble in water and is used as a germicide bleaching agent, purifier of water for swimming pools, and as a basis for military poison gas. When marketed in a liquid form it is stored in a steel cylinder, whence it escapes as a gas on releasing pressure. Chlorine is found in other chemical solutions used for cleaning. Repairman should maintain open air ventilation when working in aircraft and closed shops in order to avoid the danger of chlorine gases and vapors while cleaning equipment, floors, and parts. Special hand and body protection clothing should be worn in order to avoid skin irritations and burns.

Hydrochloric acid is a colorless, pungent smelling, poisonous liquid. It is extremely soluble in water. One of its principle uses is as a cleaning agent, since it disolves rust. Hydrochloric acid causes irritation of the mucous membranes (the moist glandular lining of certain cavities and canals of the nose). Repairman can avoid hydrochloric fumes by having open air ventilation while cleaning equipment and parts in closed shops or aircraft.

Anesthetics

Anesthetic gases and vapors have a narcotic or drug-like effect that causes partial or complete loss of sensation. This can cause a malfunction of the central nervous system. A malfunction of the central nervous can cause respiratory failure. Practically all narcotic gases and vapors belong to the hydrocarbon series. Some of the most common types are methyl alcohol, propane, and carbon tetrachloride.

Methyl alcohol causes an acute dizziness, stupor, cramps, digestive disturbances, dilated pupils, and blue lips. It also causes depression, tremors, anc chronic poisoning. Repairman working around aircraft and vehicles should take all precautionary measures to avoid the danger of methyl alcohol. Methyl alcohol is used in anti-freeze solutions.

Propane is a hydrocarbon gas of the methane series. It is used as a fuel for some vehicles and small hand-held torches. It is toxic and produces narcosis. Because it is highly flamable, you should use only the correct procedure for any device using this gas.

Carbon tetrachloride is a non-flammable liquid which causes acute headaches, nausea, vomiting, dulling of senses, permanent liver damage, and loss of consciousness. Repairmen might encounter this substance in cleaning solvents. Open air ventilation is required when this substance is used. Anesthetic gases and vapors are common in cleaning solutions, therefore, repairmen should take necessary precautions.

### CATHODE RAY TUBES

Extreme caution should be exercised by the technician when handling cathode-ray tubes. The glass envelope encloses a high vacuum, and because of its large surface area, it is subject to considerable force.

To avoid serious injury, adequate precautions should be taken at all times to minimize the danger of breaking the glass envelope. Avoid scratching, striking, or using excessive force when handling the tube or when placing it in its deflecting yoke or socket. Never hold the tube by its narrow neck. When setting the tube down, always stand it on its face on a thick piece of felt if available.

In addition to the danger of implosion due to breakage, rough handling may also cause displacement of the electrodes within the tube. Before a CRT is discarded, the tube should be rendered harmless by breaking the vacuum seal. This can be safely done as follows:

1. Place defective tubes, face down, in an empty CRT carton.

2. Carefully break off locating pin from tube base. See figure 1-24.

3. With a small screwdriver or probe, break off tip of the glass vacuum seal.

WARNING. The chemical phosphor with which the face of the CRT is coated may be toxic. When disposing of a broken tube, be careful not to get any of this compound on hands or in the eyes.

If you receive a cut from the glass of a broken CRT tube, wash the cut with soap and water. If other injuries are received the necessary first aid will be applied. The person should be taken to the hospital as soon as possible to receive the necessary treatment. The hospital should be informed that the tube contained a chemical phosphor.

### RADIOACTIVITY

#### Types of Radiation

We are all familiar with the term radiation. A loud speaker radiates sound waves which are no more than compressions of the air surrounding the speaker and are referred to as sound waves. A radio antenna radiates radio frequency waves which are electromagnetic in nature. Electromagnetic radiation covers a frequency range from the lower audio frequencies up through cosmic rays. The cosmic rays include electron and heavy particle showers from space. There are several types of electromagnetic radiations which will cause serious injury if

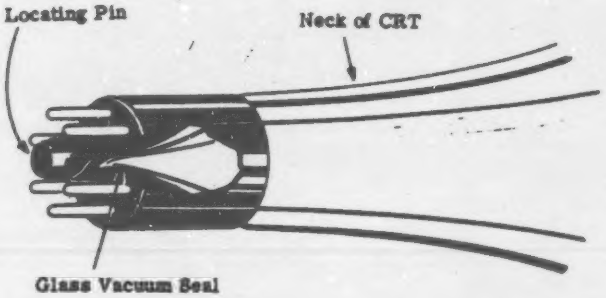


Figure 1-24. Construction of a Cathode-Ray Tube Base

personnel are exposed in excess of recommended levels. The types of radiation most often encountered are as follows:

| | |
|---|---|
| MICROWAVES | - 3000 megahertz to about 3 million megahertz. |
| X-RAYS | - 50 billion megahertz to about 100 trillion megahertz. |
| ALPHA PARTICLES | - Positive charged particles released by splitting the atom. |
| BETA PARTICLES | - Negative charged particles released by splitting the atom. |

The types of radiation described above are all high energy radiation and can cause some adverse effect on living cells and living tissue. The exact amount of damage is dependent on the form of radiation and the degree of exposure.

Sources of Radiation

Air Force personnel may encounter radiation produced by many sources on an installation - in reactors, particle accelerators, radioactive isotopes (liquids and solids), diagnostic and therapeutic X-ray machines, X-ray machines used for industrial radiography, radioactive sources used for irradiation of other materials, electronic tubes of certain types, irradiated electronic equipment, and all forms of radioactive wastes. Any material can be irradiated in a nuclear reactor and made radioactive. Therefore, it becomes important for personnel to become familiar with all sources subject to giving off radiation, if they are to guard adequately against exposure to radioactive materials. Another means of determining if radioactive substances are involved is to check the source with a radiation survey meter, or to see if the source is clearly marked with standard radiation signs and symbols.

Radioactive Substances

Unless they are present in very large quantities, alpha and beta radiation present primarily an internal hazard. These particles may be inhaled, ingested, or absorbed into the body where they will cause damage to various organs, which can ultimately result in disease and death. Alpha particles are not able to penetrate unbroken skin. Beta particles will penetrate about a third of an inch of tissue.

Preventive Measures and Handling

In order to adequately protect personnel from radioactive material, it is necessary to guard against contamination of the person's clothing, and surrounding equipment and materials. Safeguards against radioactive contamination are similar to those used against any toxic gas or dust. Adequate protective clothing, hoods, respirators, gloves, boots, and other equipment should be worn when working with or near radioactive materials or contaminated equipment. The object of protective clothing is not to cut down the radiation coming from outside the body, but rather to keep radioactive dirt or dust from being deposited on the personal clothing of workmen where it might be unknowingly spread to clean areas and subsequently find its way into the body. Personnel constantly exposed to radiation should be carefully monitored by the Base Surgeon. For positive radiation identification and safety, all personnel who are routinely exposed to radiation should wear film badges. This badge should be worn on the outside of clothing, i.e., clipped to the collar, breast pocket, shirt opening, or belt. The type of dosimeter used will be determined by the nature and intensity of the radiation to which personnel will be exposed.

AFM 32-3, "Accident Prevention Handbook" lists the following precautionary procedures to be followed by all personnel exposed to radioactive aircraft.

A thorough medical examination will be given before exposure and as often as necessary thereafter.

Proper safety instructions will be given by the base Medical Service before maintenance personnel begin operations on contaminated aircraft.

Protective clothing and a badge or dosimeter will be worn at all times during exposure.

Personnel working in a contaminated area will not smoke, eat, or chew gum.

Hands and face will be washed after working on contaminated aircraft and before eating and/or smoking.

Personal articles such as watches and rings will not be worn while working in a contaminated area or on an exposed aircraft.

Maintenance personnel who have been exposed to radiation will not handle telephones, reports, or other articles while wearing protective gloves.

When an aircraft is suspected of being contaminated, it will be taxied away from hangars, traffic, equipment, and other aircraft after landing. The aircraft will then be monitored to determine the extent of contamination and marked with AFTO Form 9, showing the standard radiation hazard warning emblem. The aircrew, their personal belongings, and clothing will also be monitored and processed as directed by assigned monitoring personnel.

Care should be exercised in the handling of containers used to store or transport nuclear or radioactive materials. If such containers become damaged, the containers and/or radioactively contaminated items should be monitored by attending radiological personnel. The immediate area should be monitored and decontaminated, if necessary.

As determined necessary by the Base Medical Service, a change house should be set up in which personnel involved in the processing of radioactively contaminated material will wash or bathe, if necessary, and change clothes. The change station may consist of existing restroom facilities and should be designated and posted to indicate a "clean-locker area"; "a wash-up and/or shower facility", and a "contaminated" area for removing contaminated clothing.

Adherence to good personal hygiene practices (such as washing of hands and face before eating or smoking) is mandatory.

### First Aid

All injuries occurring during decontamination operations or during the handling or reworking of contaminated material should be reported to the monitor immediately. The monitor will be responsible for informing Base Medical Service of such accidents immediately so that proper treatment may be given.

## MICROWAVE RADIATION

### Characteristics and Effects

Radiant energy is produced by the conversion of matter from one form to another and results in a wave motion characterized by its frequency. The term "microwave" applies to the range of frequencies ranging from about three hundred megacycles per second to around 3 million megacycles per second. This frequency band was tremendously developed during World War II, and this development continues to be carried forward with expanding energy. The low frequency portion has now entered into the more or less standard radio and communications technology, while the very highest frequency portions are in the experimental stage.

New developments in technology have brought about higher power radar with frequencies in the microwave band. A repairman is subject to encounter microwave radar at one time or another. Therefore, it is necessary for him to know some of the effects, precautions, and limitations of microwave radiation. Electromagnetic radiation (microwave radiation) from modern airborne and ground equipment may have a detrimental effect on the human body. This fact need not be alarming if personnel look at the problem squarely and intelligently. Man can handle radiation as he has handled fire - with caution and common sense.

The biological effect of microwave radiation has recently become a matter of interest and concern to personnel who come in contact with modern electronic equipment. Exposure of the human body to strong sources of microwave radiation is a subject which has been under investigation for a number of years. As far back as 1945 when radar devices first came into widespread use, studies were made to determine if any biological damage could be produced by exposure to microwave radiation from radar equipment. The results were negative. However, more recent investigations have shown that sources of power from radar devices have been developed within the last few years which are capable of producing radiation of sufficient intensity to cause damage to human tissue. High intensity radar devices have been incorporated and are used today in airplanes and ground installations used for the defense of America, Far East, and Eastern Europe.

In some respects a comparison can be drawn between microwave radiation and fire, because both are capable of burning the human body. The first time man experimented with fire and determined that it could harm him, he learned to avoid all contact with flame and incandescent substances. Now that man is confronted with a new kind of fire, microwave radiation, he must again learn to protect himself. However, man finds himself at a disadvantage in attempting to protect himself against microwave radiation because it is difficult for him to detect its presence. Radiation cannot be seen, therefore, a repairman must rely on his sense of feel, or better, his knowledge as to exactly what microwave radiation is where it comes from, how it harms, and how close he can come to it before he gets burned.

There are two types of radiation produced by electronic equipment, microwave and X-ray. At this time, only microwave radiation will be discussed. Electromagnetic radiation emitted by radar antennas, is called microwave radiation or more simply, microwave. As mentioned in the early part of this section; microwaves are classified in a band - just above radio waves in the electromagnetic spectrum.

Radiation can either be absorbed or reflected by an object in the direct path of a microwave beam. The total amount of radiation absored or reflected depends on the types of material being used and the frequency and power intensity of the microwave beam. Microwaves from modern radar units reach power intensities which may produce some startling effects. For example, under certain circumstances, dry steel wool can be ignited by a radar beam, and photoflash bulbs have been set off at distances up to 350 feet. An electric potential can build up between two metal particles and cause an arc. The arc may ignite fuel vapors.

Microwaves produce localized heating when they are absorbed by matter. This heating effect can cause biological damage to the human body if excessive amounts of radiation are absorbed. The amount of temperature rise in the body is related to the power intensity and frequency of radiation. The human eye is especially susceptible to selective heating (microwave radiation). Most parts of the body send a warning to the brain in the form of pain before enough heat is absorbed to cause biological damage. The internal eye is less sensitive than other parts of the body and is capable of absorbing more heat before pain is felt.

The depths to which radiation can penetrate the human body is largely dependent on the frequency of the micorwaves themselves, and the absorptive properties of human tissue. (See figure 1-25.) When radiation is absorbed in any of the layers, heat is produced. However, the skin layer contains most of the body's sensory elements, and if it is this layer which is absorbing

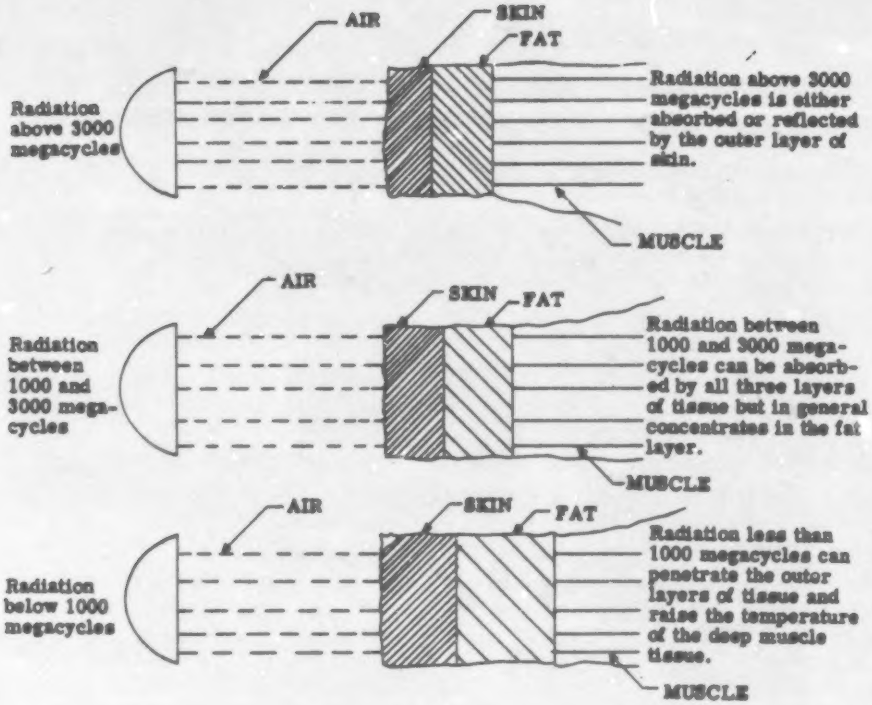

AIR
SKIN
FAT
Radiation above 3000 megacycles
Radiation above 3000 megacycles is either absorbed or reflected by the outer layer of skin.
MUSCLE
AIR
SKIN
FAT
Radiation between 1000 and 3000 megacycles
Radiation between 1000 and 3000 megacycles can be absorbed by all three layers of tissue but in general concentrates in the fat layer.
MUSCLE
AIR
SKIN
FAT
Radiation below 1000 megacycles
Radiation less than 1000 megacycles can penetrate the outer layers of tissue and raise the temperature of the deep muscle tissue.
MUSCLE

Figure 1-25

the energy, there is little danger of over exposure because an over heating warning is immediately sent to the brain. Exposing the body to microwave radiation in the frequency range above, 3000 megacycles is somewhat similar to an exposure to sunlight or infrared light.

Preventive Measures

The most important thing to consider when determining the necessary safety precuations to be taken when working near microwave radar equipment is that the energy level, or power density, measured in watts per square centimeter, is high at the source of emission (the antenna) and diminishes as the distance from the source increases. At a given distance from a transmitting radar antenna, power densities are much higher in the beam of a stationary antenna than they are when the antenna is scanning. Also, different classes of radar sets produce different power densities at given distances from their antennas.

1. Do not make a close visual inspection of any microwave radiator, reflector, waveguide opening, or waveguide horn during periods of transmission.

2. Do not make a close visual inspection of an operating klystron except through a leaded glass window or by remote viewing.

3. Absorbent screening material such as dummy loads or water loads should be provided to contain the primary beam of a microwave radiator whenever possible.

4. The number of personnel where radar components are being tested should be limited to the number required to accomplish a given test.

5. Some ECM antennas on airplanes are capable of transmitting frequencies below 1000 megacycles. Personnel should, therefore, be aware that a transmitting ECM antenna, depending on its frequency, will not always indicate its radiation level by affecting the sensory elements of the skin.

### First Aid

At this time there is no immediate first aid except that if a person is standing close to operating radar antennas he will be able to feel the heat generated in the skin layer of the exposed portion of the body. This is the body's warning signal and the person should move away from the antenna.

## X-RAYS

### Sources

High-power radar and communications equipment have created new radiation hazards. Modern electron tubes, such as high-power klystrons, magnetrons, thyratrons, cathode-ray tubes, and high-voltage rectifiers, when operated with electric potentials in excess of 16 kv, may generate X-rays. These rays may emanate from the tube if satisfactory shielding is not provided. The ability of X-rays to penetrate solid matter and modify, damage, and destroy living tissue not only makes this energy useful for medical treatments, but also makes it a hazard when not controlled.

### Effects

All X-rays, except those of very low energy, will penetrate human tissue and form positive and negative ions. These ions will cause tissue damage, which may be either temporary or permanent. Unless the dosage is extremely high, there will be no noticeable effects for days, weeks, or, in some cases, years after the exposure. This delay in effect is no doubt the most important reason for cases of overdose of X-rays, since by the time the symptoms are evident the damage has been done. Some of the known effects of overexposure to X-rays are:

1. An increase in the number of white blood cells (leukemia), a decrease in the number of white blood cells (leucopenia), increased blood clotting time, and anemia. These effects on the blood lower the resistance of the body to bacteria, which is a secondary hazard to overexposure.

2. Bone damage. Most of the damage is to the marrow, which produces the blood cells, but the bones themselves are sometimes damaged.

3. Skin cancer, skin inflammation, and loss of hair. A reddening of the skin is one of the first symptoms of overexposure.

4. Mutations. These may not appear until the second or third generation.

5. Ulcers.

6. Sterility.

7. Cataracts.

### Protection

When working with high-voltage electron tubes capable of producing X-rays, you should make certain that the radiation has been checked at all possible points of emission. Under normal operating conditions, there will probably be proper shielding for these tubes, but you should be aware of the possible increase in radiation under unusual conditions. Areas exposed to radiation should be checked to determine the radiation strength and, if necessary to set some time limits for workers in the area. The recommended maximum intensity levels in controlled radiation areas is 100 milliroentgens per week or 2.5 milliroentgens per hour. Although these limits are considered safe, you should not subject yourself to any more exposure than necessary.

Film badges or pocket meters should be worn in all radiation areas. This type of detector should be used with the understanding that radiation may be concentrated on some portion of your body where the detector is not carried. Several types of portable devices are available for monitoring or measuring radiation; these include ionization chambers, proportional counters, Geiger-Meuller counters, scintillation detectors, and electroscopes. An instrument with a separate probe is useful for checking high-voltage tubes, particularly when areas of restricted size must be reached.

## RADIOACTIVE TUBES

### General

Electron tubes containing radioactive material are now commonly used in radar equipment. These tubes are known as tr, atr, spark-gap, glow-lamp, and cold-cathode tubes. Radioactive material is intentionally added to these tubes to produce a continuous supply of ionized particles. This ensures that the gas within the tube will always ionize at the same voltage. The principal radioactive materials contained in tubes and the intensity levels which should be considered as dangerous, and so marked, are listed in table 1-1.

Table 1-1

INTENSITY LEVELS FOR RADIOACTIVE COMMODITIES TO BE MARKED "DANGER"

| MATERIAL | INTENSITY (Microcuries) |
|---|---|
| Carbon 14 (C 14) | 5.0 |
| Cesium-Barium 137 (CsBa 137) | 1.0 |
| Cobalt 60 (Co 60) | 1.0 |
| Nickel 63 (Ni 63) | 1.0 |
| Radium 226 (Ra 226) | 0.1 |

### Atomic Radiation Hazards

As long as a tube containing radioactive material is not broken, the hazard is slight. The concentration of radioactivity in a normal collection of electron tubes at maintenance shopes does not approach a dangerous level. However, at major supply points, the storage of large quantities of radioactive tubes in a relatively small area may create a hazard. A broken radioactive tube immediately becomes a hazard, since radioactive material may enter a person's body by inhalation, through the skin by way of an open wound, and with food. Radioactive material deposited within the person's body produces internal radiation which may injure or destroy blood-forming organs and body tissue. The removal of this hazard is limited by the rate of excretion of the elements from the body and the natural radioactive decay of the material. The degree of injury depends primarily on the quantity of radiation energy absorbed by the body cells. If only a small amount of radioactive material is absorbed by the body, symptoms of internal injuries may not appear for years. Table 1-2 lists tubes that are known to contain radioactive material, the type of radioactive material, and the intensity of radioactivity of each tube.

### Precautions

The following practices should be observed to minimize the danger presented by radioactive tubes.

1. Tubes should not be removed from cartons until immediately prior to actual installation. This serves two purposes: to prevent accidental breakage, and to avoid the possibility of concentrating several radioactive tubes in a small volume (which would increase the effective intensity of radiation).

2. When a tube is removed from equipment, it should be placed in an appropriate carton to prevent pasible breakage.

# Table 1-2

## TUBES CONTAINING RADIOACTIVE MATERIAL

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| OA2 | Co 60 | 0.0067 |
| OA2WA | Ni 63 | 0.01-.05 |
| OA2WA | Co 60 | 0.0067 |
| OB2 | Co 60 | 0.0067 |
| OB2WA | Ni 63 | 0.01-.05 |
| OB2WA | Co 60 | 0.0067 |
| 1B22 | Co 60 | 0.25 |
| 1B23 | Co 60 | 0.15 |
| 1B23 | Co 60 | 0.5-1.0 |
| 1B24 | Ra 226 | 2.0 |
| GL-1B24A | Co 60 | 0.475 |
| 1B24A | Co 60 | 0.15 |
| 1B24A | Co 60 | 0.5 |
| 1B24A | Co 60 | 1.0 |
| 1B24A | Ra 226 | 2.0 |
| 1B26 | Co 60 | 0.15 |
| 1B27 | Co 60 | 0.15 |
| 1B31 | Co 60 | 0.25 |
| GL-1B35A | Co 60 | 0.950 |
| 1B35A | Co 60 | 0.4 |
| 1B35A | Co 60 | 1.0 |
| 1B36 | Co 60 | 0.25 |
| 1B36 | Co 60 | 0.950 |
| GL-1B37A | Co 60 | 0.4 |
| 1B37A | Co 60 | 1.0 |
| GL-1B38 | Co 60 | 0.475 |
| 1B38 | Co 60 | 0.9 |
| 1B40 | Co 60 | 0.2 |
| 1B40 | Co 60 | 1.0 |
| 1B41 | Co 60 | 0.25 |
| 1B41 | Ra 226 | 2.0 |
| GL-1B44 | Co 60 | 0.475 |
| 1B44 | Co 60 | 0.45 |
| 1B44 | Co 60 | 1.0 |
| 1B45 | Co 60 | 0.25 |
| 1B45 | Ra 226 | 2.0 |
| 1B49 | Ra 226 | 4.0 |
| 1B50 | Co 60 | 0.15 |
| 1B51 | Co 60 | 0.4 |
| 1B52 | Co 60 | 0.45 |
| 1B53 | Co 60 | 0.45 |

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| 1B54 | Co 60 | 0.45 |
| 1B55 | Co 60 | 0.5 |
| GL-1B56 | Co 60 | 0.475 |
| 1B56 | Co 60 | 0.45 |
| 1B57 | Co 60 | 0.475 |
| GL-1B58 | Co 60 | 0.475 |
| 1B58A | Co 60 | 0.5 |
| 1B60 | Co 60 | 0.15 |
| 1B60 | Ra 226 | 2.0 |
| 1B62 | Co 60 | 0.15 |
| GL-1B63 | Co 60 | 0.475 |
| GL-1B63A | Co 60 | 0.475 |
| 1B63A | Co 60 | 0.15 |
| 1B63A | Co 60 | 0.5 |
| 1B63A | Co 60 | 1.0 |
| 1B63B | Co 60 | 0.15 |
| TG-6 | Cs 137 | 5.0 |
| BL-6 | Co 60 | 0.15 |
| TG-8 | Cs 137 | 5.0 |
| TD-9 | Ra 226 | 0.5 |
| BL-10 | Co 60 | 0.15 |
| TG-11 | Cs 137 | 5.0 |
| TG-12 | Cs 137 | 5.0 |
| TG-13 | Cs 137 | 5.0 |
| TG-14 | Cs 137 | 5.0 |
| BL-15 | Co 60 | 0.25 |
| TG-15 | Cs 137 | 5.0 |
| BL-16 | Co 60 | 0.15 |
| TG-16 | Cs 137 | 0.5 |
| TD-19/6142 | Ra 226 | 0.5 |
| BL-20 | Co 60 | 0.15 |
| BL-29 | Co 60 | 0.15 |
| BL-34 | Co 60 | 0.5 |
| BL-36 | Co 60 | 0.45 |
| BL-36A | Co 60 | 0.9 |
| BL-39 | Co 60 | 0.15 |
| BL-40 | Co 60 | 0.45 |
| BL-41 | Co 60 | 0.45 |
| BL-44 | Co 60 | 0.15 |
| BL-45 | Co 60 | 0.4 |
| BL-47 | Co 60 | 0.15 |

## Table 1-2 (Cont'd)

## TUBES CONTAINING RADIOACTIVE MATERIAL

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| BL-49 | Co 60 | 0.4 |
| BL-51 | Co 60 | 0.15 |
| BL-52 | Co 60 | 0.4 |
| BL-57 | Co 60 | 0.15 |
| BL-58 | Co 60 | 0.15 |
| BL-59 | Co 60 | 0.9 |
| BL-63 | Co 60 | 0.5 |
| BL-64 | Co 60 | 0.15 |
| BL-66 | Co 60 | 0.15 |
| BL-69 | Co 60 | 0.4 |
| BL-70 | Co 60 | 0.4 |
| BL-72 | Co 60 | 0.4 |
| BL-73 | Co 60 | 0.4 |
| BL-74 | Co 60 | 0.4 |
| BL-75 | Co 60 | 0.4 |
| BL-76 | Co 60 | 0.4 |
| BL-77 | Co 60 | 0.7 |
| BL-78 | Co 60 | 0.25 |
| BL-79 | Co 60 | 0.15 |
| BL-80 | Co 60 | 0.15 |
| BL-82 | Co 60 | 0.15 |
| BL-83 | Co 60 | 0.4 |
| BL-84 | Co 60 | 0.25 |
| BL-84H | Co 60 | 0.25 |
| BL-85 | Co 60 | 0.15 |
| BL-88 | Co 60 | 0.5 |
| BL-89 | Co 60 | 0.15 |
| BL-91 | Co 60 | 0.5 |
| BL-92 | Co 60 | 0.4 |
| EP-93 | C 14 | 3.0 |
| BL-97 | Co 60 | 0.9 |
| BL-98 | Co 60 | 0.9 |
| VXR-130 | Ni 63 | 0.001 |
| BL-302 | Co 60 | 0.25 |
| BL-303 | Co 60 | 0.15 |
| MA-303 | Co 60 | 1.0 |
| BL-304 | Co 60 | 0.15 |
| MA-304 | Co 60 | 1.0 |
| BL-305 | Co 60 | 0.15 |
| BL-306 | Co 60 | 0.15 |
| MA-306 | Co 60 | 1.0 |
| BL-307 | Co 60 | 0.25 |
| BL-308 | Co 60 | 0.15 |
| MA-309 | Co 60 | 1.0 |
| MA-311 | Co 60 | 0.5 |
| MA-312 | Co 60 | 0.5 |
| MA-313 | Co 60 | 0.5 |
| 313C | Ra 226 | 0.01 |
| 313CA | Ra 226 | 0.0005-.05 |
| 313CB | Ra 226 | 0.01 |
| 313CC | Ra 226 | 0.01 |
| 313CD | Ra 226 | 0.01 |
| MA-314 | Co 60 | 0.5 |
| MA-316 | Co 60 | 0.5 |
| MA-319 | Co 60 | 0.5 |
| MA-322 | Co 60 | 1.0 |
| BL-326H | Co 60 | 0.15 |
| BL-326 | Co 60 | 0.15 |
| BL-331 | Co 60 | 0.25 |
| BL-332 | Co 60 | 0.15 |
| BL-333 | Co 60 | 0.15 |
| 333A | Ra 226 | 0.01 |
| BL-335 | Co 60 | 0.25 |
| BL-336 | Co 60 | 0.25 |
| BL-337 | Co 60 | 0.15 |
| BL-338 | Co 60 | 0.15 |
| BL-339 | Co 60 | 0.25 |
| BL-340 | Co 60 | 0.15 |
| BL-340H | Co 60 | 0.15 |
| BL-341 | Co 60 | 0.25 |
| BL-342 | Co 60 | 0.15 |
| BL-343 | Co 60 | 0.15 |
| BL-344 | Co 60 | 0.25 |
| BL-345 | Co 60 | 0.5 |
| BL-346 | Co 60 | 0.9 |
| 346B | Ra 226 | 1.0 |
| BL-347 | Co 60 | 0.15 |
| BL-348 | Co 60 | 0.25 |
| BL-306 | Co 60 | 0.15 |
| BL-349 | Co 60 | 0.15 |
| BL-350 | Co 60 | 0.15 |
| EP-350 | Ni 63 | 3.0 |

Table 1-2 (Cont'd)

## TUBES CONTAINING RADIOACTIVE MATERIAL

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| BL-351 | Co 60 | 0.5 |
| BL-352 | Co 60 | 0.25 |
| 353A | Ra 226 | 0.01 |
| 359 | Ra 226 | 0.01 |
| 372A | Ra 226 | 0.01 |
| 376B | Ra 226 | 1.0 |
| 395A | Ra 226 | 0.01 |
| 396A | Ra 226 | 0.0006-.06 |
| VXR-400 | Ni 63 | 0.001 |
| 401 | C 14 | 1.0 |
| 402 | C 14 | 1.0 |
| 404 | C 14 | 1.0 |
| 405 | C 14 | 1.0 |
| 406 | C 14 | 1.0 |
| 411A | Ra 226 | 1.0 |
| 412 | C 14 | 1.0 |
| 413 | C 14 | 1.0 |
| 413A | Ra 226 | 1.0 |
| 414 | C 14 | 1.0 |
| 416 | C 14 | 1.0 |
| 417 | C 14 | 1.0 |
| 418 | C 14 | 1.0 |
| 419 | C 14 | 1.0 |
| 420 | C 14 | 1.0 |
| 421 | C 14 | 1.0 |
| 422A | Ra 226 | 0.01 |
| 425A | Ra 226 | 0.01 |
| 426A | Ra 226 | 0.01 |
| 427A | Ra 226 | 0.1 |
| 430A | Ra 226 | 1.0 |
| 431 | C 14 | 1.0 |
| 432 | C 14 | 1.0 |
| 432A | Ra 226 | 0.01 |
| 432B | Ra 226 | 0.01 |
| 433 | C 14 | 1.0 |
| 434 | C 14 | 1.0 |
| 435 | C 14 | 1.0 |
| 436 | C 14 | 1.0 |
| 436A | Ra 226 | 0.01 |
| 441 | C 14 | 1.0 |
| 442 | C 14 | 1.0 |
| 443 | C 14 | 1.0 |
| 443A | Ra 226 | 0.01 |
| 444 | C 14 | 1.0 |
| 445 | C 14 | 1.0 |
| 446 | C 14 | 1.0 |
| VXR-500 | Ni 63 | 0.001 |
| VXR-600 | Ni 63 | 0.001 |
| BL-601 | Co 60 | 0.5 |
| BL-602 | Co 60 | 0.15 |
| BL-603 | Co 60 | 0.5 |
| BL-604 | Co 60 | 0.25 |
| BL-605 | Co 60 | 0.15 |
| BL-606 | Co 60 | 0.4 |
| BL-607 | Co 60 | 0.25 |
| BL-608 | Co 60 | 0.4 |
| BL-610 | Co 60 | 0.4 |
| BL-611 | Co 60 | 0.15 |
| BL-612 | Co 60 | 0.3 |
| BL-613 | Co 60 | 0.15 |
| BL-614 | Co 60 | 0.15 |
| BL-617 | Co 60 | 0.25 |
| BL-618 | Co 60 | 0.3 |
| BL-619 | Co 60 | 0.5 |
| BL-620 | Co 60 | 0.15 |
| BL-621 | Co 60 | 0.15 |
| BL-622 | Co 60 | 0.5 |
| BL-623 | Co 60 | 0.45 |
| BL-624 | Co 60 | 0.25 |
| BL-625 | Co 60 | 0.25 |
| BL-626 | Co 60 | 0.3 |
| BL-627 | Co 60 | 0.25 |
| BL-628 | Co 60 | 0.3 |
| BL-629 | Co 60 | 0.5 |
| BL-630 | Co 60 | 0.45 |
| BL-631 | Co 60 | 0.25 |
| BL-632 | Co 60 | 0.3 |
| BL-633 | Co 60 | 0.45 |
| BL-634 | Co 60 | 0.3 |
| BL-635 | Co 60 | 0.15 |
| BL-636 | Co 60 | 0.25 |
| BL-637 | Co 60 | 0.3 |

## Table 1-2 (Cont'd)

## TUBES CONTAINING RADIOACTIVE MATERIAL

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| BL-638 | Co 60 | 0.9 |
| BL-640 | Co 60 | 0.9 |
| BL-641 | Co 60 | 0.4 |
| BL-642 | Co 60 | 0.45 |
| WE-642 | Ra 226 | 2.0 |
| BL-643 | Co 60 | 0.15 |
| BL-644 | Co 60 | 0.35 |
| BL-645 | Co 60 | 0.25 |
| BL-646 | Co 60 | 0.5 |
| BL-647 | Co 60 | 0.5 |
| BL-648 | Co 60 | 0.5 |
| BL-649 | Co 60 | 0.25 |
| BL-650 | Co 60 | 0.4 |
| BL-651 | Co 60 | 0.25 |
| BL-652 | Co 60 | 0.9 |
| BL-654 | Co 60 | 0.5 |
| BL-656 | Co 60 | 0.9 |
| BL-658 | Co 60 | 0.5 |
| BL-660 | Co 60 | 0.45 |
| BL-661 | Co 60 | 0.15 |
| BL-662 | Co 60 | 0.4 |
| BL-664 | Co 60 | 0.9 |
| EP-680 | Ni 63 | 3.0 |
| BL-700 | Co 60 | 0.25 |
| BL-702 | Co 60 | 0.25 |
| BL-703 | Co 60 | 0.25 |
| BL-706 | Co 60 | 0.23 |
| BL-714 | Co 60 | 0.25 |
| BL-717 | Co 60 | 0.25 |
| BL-718 | Co 60 | 0.15 |
| 721B | Co 60 | 0.25 |
| BL-724 | Co 60 | 0.15 |
| 734B | Co 60 | 0.15 |
| BL-726 | Co 60 | 0.25 |
| BL-735 | Co 60 | 0.25 |
| VXR-800 | Ni 63 | 0.001 |
| VXR-1000 | Ni 63 | 0.001 |
| 1022 | Co 60 | 0.0067 |
| VXR-1201 | Ni 63 | 0.001 |
| VXR-1401 | Ni 63 | 0.001 |
| VXR-1500 | Ni 63 | 0.001 |

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| VXR-1800 | Ni 63 | 0.001 |
| Z-1972 | Co 60 | 0.475 |
| VXR-2002 | Ni 63 | 0.001 |
| VXR-2500 | Ni 63 | 0.001 |
| VXR-3001 | Ni 63 | 0.001 |
| WX-3330 | Ra 226 | 2.0 |
| WX-3346 | Ra 226 | 2.0 |
| VXR-4000 | Ni 63 | 0.001 |
| VXR-5000 | Ni 63 | 0.001 |
| 5589 | Ra 226 | 1.0 |
| 5651 | Co 60 | 0.0067 |
| 5651WA | Ra 226 | 0.045-.055 |
| 5651WA | Co 60 | 0.0067 |
| 5783 | Co 60 | 0.0067 |
| 5783WA | Co 60 | 0.0067 |
| 5783WB | Co 60 | 0.0067 |
| 5787 | Co 60 | 0.0067 |
| 5787WA | Co 60 | 0.0067 |
| 5787WB | Co 60 | 0.0067 |
| 5790/X7106 | Co 60 | 1.0 |
| 5791/X6007 | Co 60 | 1.0 |
| 5792 | Co 60 | 0.45 |
| 5792/ATR-345 | Co 60 | 1.0 |
| 5793 | Co 60 | 0.45 |
| 5793/ATR-346 | Co 60 | 1.0 |
| 5841 | Ni 63 | 0.001 |
| 5852 | Co 60 | 0.5 |
| 5853 | Co 60 | 0.5 |
| 5853/TR-368 | Co 60 | 1.0 |
| 5854/ATR-321 | Co 60 | 0.4 |
| 5863 | Co 60 | 0.5 |
| 5863/X7106 | Co 60 | 1.0 |
| 5864/ATR-321 | Co 60 | 1.0 |
| 5865/TR-361 | Co 60 | 0.15 |
| 5865/TR-361 | Co 60 | 1.0 |
| 5883 | Co 60 | 0.4 |
| 5883/ATR-301 | Co 60 | 1.0 |
| 5921 | Co 60 | 0.45 |
| 5921/ATR-348 | Co 60 | 1.0 |
| 5922 | Co 60 | 0.45 |
| 5922/ATR-349 | Co 60 | 1.0 |

## Table 1-2 (Cont'd)

## TUBES CONTAINING RADIOACTIVE MATERIAL

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| 5925/TR-351 | Co 60 | 0.15 |
| GL-5927 | Co 60 | 0.475 |
| 5927 | Co 60 | 0.5 |
| 5927 | Co 60 | 0.5 |
| 5927/TR-351 | Co 60 | 1.0 |
| WL-5939 | Ra 226 | 2.0 |
| WL-5939A | Ra 226 | 2.0 |
| 5950 | Ni 63 | 0.001 |
| 5962 | C 14 | 1.0 |
| 5962 | Ni 63 | 3.0 |
| 5962 | Co 60 | 0.0067 |
| 5962 | Ni 63 | 0.001 |
| 6015 | Co 60 | 0.5 |
| 6022/ATR-332 | Co 60 | 0.25 |
| 6024/ATR-367 | Co 60 | 0.45 |
| 6033 | Co 60 | 0.4 |
| 6034 | Co 60 | 0.4 |
| GL-6035 | Co 60 | 0.475 |
| 6035 | Co 60 | 0.15 |
| 6061/ATR-407 | Co 60 | 0.4 |
| 6061/ATR-407 | Co 60 | 1.0 |
| 6109 | C 14 | 1.0 |
| GL-6117 | Co 60 | 0.475 |
| 6117 | Co 60 | 0.45 |
| 6117 | Co 60 | 0.5 |
| 6117 | Co 60 | 1.0 |
| 6140 | Ra 226 | 0.01 |
| 6141 | Ra 226 | 0.1 |
| 6143 | Ni 63 | 0.001 |
| 6162/ATR-388 | Co 60 | 0.4 |
| 6163 | Co 60 | 0.4 |
| 6163 | Co 60 | 0.5 |
| 6163/ATR-428 | Co 60 | 1.0 |
| 6164 | Co 60 | 0.15 |
| 6164 | Co 60 | 0.5 |
| 6164/TR-429 | Co 60 | 1.0 |
| 6167 | Ra 226 | 0.01 |
| 6213 | Co 60 | 0.0067 |
| 6214 | Co 60 | 0.4 |
| 6214/ATR-426 | Co 60 | 1.0 |
| 6232/ATR-427 | Co 60 | 0.15 |
| 6232 | Co 60 | 0.5 |
| 6232/TR-427 | Co 60 | 1.0 |
| WL-6260 | Ra 226 | 2.0 |
| 6262/BL-11 | Co 60 | 0.15 |
| 6264 | Co 60 | 0.4 |
| 6304/BL-43 | Co 60 | 0.4 |
| 6322/ML-25 | Co 60 | 0.15 |
| 6334/BL-27 | Co 60 | 0.25 |
| 6334 | Co 60 | 1.0 |
| 6334 | Co 60 | 1.0 |
| 6368 | Co 60 | 0.15 |
| 6369 | Co 60 | 0.4 |
| WL-6376 | Ra 226 | 2.0 |
| 6378/BL-62 | Co 60 | 0.13 |
| 6392/BL-63 | Co 60 | 0.4 |
| 6395 | Co 60 | 0.4 |
| 6396 | Co 60 | 1.0 |
| 6437/1037 | Co 60 | 0.0067 |
| 6438/1039 | Co 60 | 0.0067 |
| 6455/BL-61 | Co 60 | 0.25 |
| 6542 | Co 60 | 0.0067 |
| 6545 | Co 60 | 1.0 |
| 6546 | Co 60 | 1.0 |
| 6560/BL-35 | Co 60 | 0.25 |
| 6564/BL-71 | Co 60 | 0.25 |
| 6565/BL-313 | Co 60 | 0.15 |
| 6565 | Co 60 | 0.5 |
| 6566/BL-26 | Co 60 | 0.15 |
| 6591 | Co 60 | 0.4 |
| 6591 | Co 60 | 1.0 |
| 6592/BL-309 | Co 60 | 0.15 |
| 6593/BL-310 | Co 60 | 0.15 |
| 6594/BL-311 | Co 60 | 0.15 |
| 6595/BL-316 | Co 60 | 0.13 |
| 6596/BL-317 | Co 60 | 0.25 |
| 6597/BL-320 | Co 60 | 0.15 |
| 6599/BL-322 | Co 60 | 0.25 |
| 6600/BL-323 | Co 60 | 0.15 |
| 6601/BL-327 | Co 60 | 0.25 |
| 6602/BL-329 | Co 60 | 0.5 |
| 6613/BL-324 | Co 60 | 0.25 |

## Table 1-2 (Con't)

## TUBES CONTAINING RADIOACTIVE MATERIAL

| TUBE TYPE | ISOTOPE | QUANTITY PER TUBE (Microcuries) |
|---|---|---|
| 6613A | Co 60 | 1.0 |
| 6614/BL-314 | Co 60 | 0.15 |
| 6615/BL-312 | Co 60 | 0.15 |
| 6616/BL-326 | Co 60 | 0.15 |
| 6624/BL-653 | Co 60 | 0.25 |
| 6624 | Co 60 | 1.0 |
| 6626/OA2WA | Ni 63 | 0.01-0.05 |
| 6627/OB2WA | Ra 226 | 0.095-0.055 |
| 6627/OB2WA | Ni 63 | 0.01-0.05 |
| 6628/BL-32 | Co 60 | 0.9 |
| 6629/BL-54 | Co 60 | 0.4 |
| 6630/BL-55 | Co 60 | 0.4 |
| 6631/BL-94 | Co 60 | 0.4 |
| 6632/BL-18 | Co 60 | 0.9 |
| 6633/BL-37 | Co 60 | 0.9 |
| 6634/BL-90 | Co 60 | 0.9 |
| 6635/BL-57 | Co 60 | 0.15 |
| 6636/BL-87 | Co 60 | 0.9 |
| 6637/BL-31 | Co 60 | 0.15 |
| 6638/BL-99 | Co 60 | 0.15 |
| 6639/BL-46 | Co 60 | 0.15 |
| 6640/BL-60 | Co 60 | 0.4 |
| 6641/BL-66 | Co 60 | 0.25 |
| 6642/BL-600 | Co 60 | 0.25 |
| 6643/BL-61 | Co 60 | 0.25 |
| 6644/BL-95 | Co 60 | 0.15 |
| 6645/BL-95H | Co 60 | 0.15 |
| 6646/BL-604 | Co 60 | 0.25 |
| 6647/BL-604H | Co 60 | 0.25 |
| 6648/BL-614 | Co 60 | 0.25 |
| 6649 BL-56 | Co 60 | 0.15 |
| 6650/BL-67 | Co 60 | 0.15 |
| 6685/BL-616 | Co 60 | 0.25 |
| 6795 | Co 60 | 0.15 |
| 6795 | Co 60 | 1.0 |
| 6796 | Co 60 | 0.25 |
| 6797 | Co 60 | 0.25 |
| 6830 | Ni 63 | 0.01-0.05 |
| 6831 | Ni 63 | 0.01-0.05 |

3. These tubes should never be carried in a pocket or elsewhere about you in such a manner that breakage can occur.

4. Extreme care should be exercised in the handling of these tubes while installing or removing them from equipment.

5. If breakage does occur, material contaminated by radioactivity should not be allowed to come in contact with any part of your body at any time. Take care to avoid breathing any vapor or dust (such as radon gas, a highly radioactive substance) which may be released by such breakage. Immediately locate all broken pieces, and isolate the area until the broken pieces have been removed or declared nonradioactive by test with an adequate radiation-sensitive device.

6. No food or drink should be brought into the contaminated area or near any radioactive material.

7. Immediately after leaving a contaminated area, personnel who have handled radioactive material in any way should remove contaminated clothing. They should wash their hands and arms thoroughly with soap and water, especially before eating, drinking or smoking.

### First Aid

When a wound caused by a sharp radioactive object is sustained, mild bleeding should be stimulated by pressure about the wound and the use of suction bulbs. Do not suck the wound by mouth. Wash the wound with soap, and flush with plenty of clean water. If the wound is of the puncture type, or the opening is small, make an incision to promote free bleeding and to facilitate cleaning and flushing of the wound.

### Decontaminating Surfaces

When cleaning a contaminated area, you should wear rubber or plastic gloves. Large fragments of a broken tube should be removed with the aid of some tool, such as forceps, if they are available. The remaining particles can be removed with a vacuum cleaner, using a disposal collecting bag, or by wiping a wet cloth across the area. If a wet cloth is used, make one stroke at a time, and fold the cloth in half after each stroke, always using a clean side. When the cloth becomes too small, discard it and continue with a clean piece. Be careful not to rub the radioactive particles into the surface by using a back-and-forth motion. All debris, cloths, and bags used for cleaning should be sealed in a container such as a plastic bag, heavy waxed paper, or glass jar, and placed in a steel can for disposal. Radioactive waste can be disposed of by burying in soil or in the ocean.

## SOLDERING HAZARDS

### General

Soldering is a safe process if the hazards associated with soldering are recognized and normal safety precautions are observed. The possible sources of danger to personnel and property are from heat, fire, electricity, fumes, and chemicals.

Since soldering is a process which requires heat, the risk of receiving painful and dangerous burns is always present. Burns can be received from the primary source of heat, from explosions caused by open flames, and from handling soldered metals before they have cooled sufficiently. Burns are a personnel problem and can be avoided by thorough training.

Closely associated with the dangers of heat is the fire hazard. Fires can cause extensive property damage, and frequently are the cause of loss of life or injury to personnel. Soldering electronic equipment presents little danger from fire except for the possibility of an electrical fire caused by overloaded supply circuits or a short circuit. However, the equipment used for general-purpose soldering present a definite fire hazard at all times. Fires can result from the careless handling of flame heating devices, or from their use in the vicinity of inflammable fumes and liquids. Fire hazards can be decreased greatly by observing simple safety precautions.

Volatile fumes are a hazard both to personnel and property; however, the danger can be decreased during soldering operations if adequate ventilation is provided. Fumes from gasoline and alcohol present an explosion hazard, since they can be ignited by an open flame or by a spark. Combustible gas mixtures, such as oxygen and acetylene, present the same type of danger. Other fumes may be injurious to the health of operating personnel. For example, fumes from heated fluxes and from degreasing liquids can cause lung and skin irritations.

Since electrical soldering equipment is so widely used, an electrical hazard to associated supply circuits can cause fires and explosions under certain conditions. This hazard can be minimized by the use of equipment in good condition and by not overloading the electrical circuits. As with all electrical equipment, the danger of electrical shock to operating personnel is present.

Chemicals which may present a health hazard are used extensively in soldering fluxes and degreasing solution. Noncorrosive fluxes present little problem, but the alkalies and acids used in corrosive fluxes may cause skin irritations and burns. Danger to the eyes also exists, since many of the chemicals are in liquid solutions, and splashing or spattering may occur. The hazard presented by chemicals is slight if proper safety precautions are observed.

### Protection

GENERAL. Many precautions are common to all types of soldering. They must be observed to prevent personnel injuries and damage to property.

1. Do not solder electronic equipment unless it is disconnected from the supply circuit. Serious burns can be received by contact with RF circuits. Death can result from contact with a high-voltage source.

2. Ground all equipment to lessen the danger of electrical shock.

3. Do not overload electrical circuits, because of the danger of fire.

4. Ground electric soldering irons and guns to eliminate the danger of electric shock resulting from defective equipment.

5. Do not flip excess solder from the tip of a hot soldering iron. Bits of hot solder can cause serious skin and eye burns; they may also ignite combustible materials.

6. To avoid painful burns, handle hot metals with care. In addition, completed soldered assemblies may be dropped and damaged by handling them when they are hot.

7. Select the proper working area for soldering. Choose a well-ventilated location away from all fire hazards.

8. Hold large workpieces securely while they are being soldered. Severe injuries or burns may be received because of a falling workpiece.

9. Wear the proper clothing and protective devices while soldering.

10. Maintain a clean working area to prevent fires. Remove combustible materials from the floor and from the surrounding area.

11. Keep fire-fighting devices and first aid supplies near the soldering area. All equipment should be checked at regular intervals.

### Electric Soldering Devices

Two types of soldering guns are in common use today; they differ mainly in the manner in which the tip is heated. One type consists of a conventional soldering iron tip and heating element mounted in a gun-type handle; a trigger switch may or may not be included to control the period of heating. Since the characteristics of this type of soldering gun so closely resemble those of the soldering iron, it will not be discussed further. The other type of soldering gun operates on the transformer principle. The handle of the soldering gun contains a transformer whose secondary circuit is completed through a loop-style tip. The point of the tip is heated by the passage of large secondary currents at low voltages. The gun is operated by depressing a trigger switch. Thus, heating occurs only when the switch is operated, and the tip is protected against damage caused by overheating. The gun is characterized by its fast heating rate.

The following precautions should be observed when using electric soldering devices:

1. Do not permit a hot soldering iron to rest on a wooden bench or chair. Use a soldering iron holder.

2. Furnaces and induction heating units operate with high currents. They must be connected and operated according to the appropriate instructions. Do not contact current-carrying conductors or connections when such equipment is operating, or death from electric shock may result.

### Flame-Heated Soldering Devices

Flame-heated soldering devices obtain their heat from the burning of various gases and combustible vapors. They are particularly useful for soldering large joints, such as those found in water-cooling plumbing lines for high-power electron tubes which cannot be heated effectively with a soldering iron. This equipment cannot be used to solder joints in electrical and electronic equipment because the flame cannot be confined to small areas. In addition, the flame temperature cannot be controlled readily. However, in an emergency, a gas-operated torch or burner can be used to heat a soldering iron; the iron can then be used to make small joints.

The following precautions should be observed when using flame-heated soldering devices:

1. Store combustible gas cylinders in a protected and well-ventilated area. The storage area should be located away from all sources of heat that could be a fire hazard. Do not store oxygen and combustible gas cylinders in the same location, because of the explosion hazard.

2. Transport gas cylinders to and from the working area with a hand truck or cart. The valve-protection caps must be mounted on the cylinders while they are being moved; never move a cylinder when the valve is open. Do not lift a cylinder by the valve-protection cap with a crane; use an approved cradle or holder.

3. Install gas cylinders upright in a rack or stand, to prevent them from falling. Do not fasten cylinders to radiators or pipings to which electrical equipment may be grounded; a spark could cause an explosion. Install cylinders in a well-ventilated area, away from heat and combustible materials.

4. Use approved pressure regulators to reduce the cylinder pressure to working limits.

5. Use the proper hose to connect the blowpipe to the gas cylinders. Handle the hose carefully to avoid scuffs and other damage. Do not lay the hose where it can be run over. Inspect the hose for damage at regular intervals.

6. Do not permit oxygen to come in contact with oily materials, because of the danger of fire. Do not put oil on regulator or blowpipe fittings.

7. Do not adjust acetylene gas pressure to exceed 15 pounds per square inch, or an explosion may occur.

8. Observe normal safety precautions in operating blowpipes. Do not allow the flame to contact combustible materials. Avoid burns.

9. Close the valves on the blowpipe and cylinder valves, and disconnect the hose, blowpipe, and regulators if further soldering is not to be done in the immediate future. Replace the valve protection caps on the cylinders.

## MECHANICAL DEVICES

### General

The hazards to the safety of personnel with respect to machinery seem to be well known to everyone in general; yet, in an unguarded second, serious injury or death occurs. Personnel can be prevented from entering a dangerous situation by establishing physical barriers around operating machinery and/or by mental discipline of personnel. However, when such machinery becomes defective, the physical barriers that provided personnel safety are immediately removed for access purposes. In the final analysis, it is the mental discipline which provides the greatest protection.

### Rotating Machinery

Motor-generators and any other rotating equipments which are installed in a communications-electronics installation must have their rotating parts covered, so that it will be impossible for the clothing, fingers, or limbs of attending personnel to become entangled or caught in the moving parts. It is the responsibility of all personnel to make sure that covers, guards, and barriers are kept in place and that the rules governing placement are not violated. No equipment should be accepted for normal service usage unless the covers and guards are in place.

Rotating machinery is often viewed in operation by means of a stroboscope, to determine rotational speeds, etc. The illusion of stopped mechanical motion is very convincing under these circumstances. Do not attempt to touch the moving equipment.

The arrangement of your clothing must also be taken into account when you are working around rotating machinery. Your necktie, if worn, ust be securely fastened to your shirt. Your shirt sleeves should not be left unbuttoned and dangling; they should be buttoned at the cuff or rolled up. Your shirt tails should be securely tucked inside your trousers instead of left dangling where they can become caught in moving machinery.

## TOXIC AGENTS

### General

Toxic hazards are those dangers to human safety due to possible contact with or proximity to poisonous substances. Some poisonous substances are termed "caustic" or "corrosive," and cause the flesh to be eaten away; the results of contact with these agents range from minor skin irritations to severe burns. There are a wide variety of materials in daily usage that are toxic only if they are taken internally, mostly caused by inattention and/or lack of personal hygiene. Some poisons exist as a gaseous vapor and may be injurious immediately or over a long period of time. There are also a few substances used in electronic equipments that are basically nontoxic agents, but under certain conditions, can become highly toxic.

### Degreasing Solvents

CARBON TETRACHLORIDE. Never use carbon tetrachloride as a degreasing agent if you can avoid it. As a liquid, carbon tetrachloride destroys the natural oils of the skin, producing a whitish appearance on skin surfaces that are exposed; continuous skin exposure may cause skin eruptions as a result of defatting action.

Carbon tetrachloride vapors cause depression of the central nervous system and extensive damage to the liver and kidneys. Prolonged exposure results in listlessness, headache, nausea, dizziness, and confusion, which may be followed by stupor and sometimes loss of consciousness.

If carbon tetrachloride is heated it decomposes to form toxic gases, such as phosgene and chlorine.

TRICHLORETHANE. This agent, used principally as a degreasing solvent, is a narcotic and anesthetic material. Organic injury rarely results from exposure. Chronic overexposure can cause anemia and liver damage.

TRICHLORETHYLENE. This agent, used principally as a degreasing solvent, is a narcotic and anesthetic material. Organic injury rarely results from acute overexposures, but the chronic accumulation of overexposure can cause anemia and liver damage.

### Pressurizing Gases

Sulphur hexafluoride is a gas of high dielectric strength at microwave frequencies. It is basically a nontoxic gas; however, the heat generated by electric currents in the waveguide will cause a partial decomposition of the gas, which is toxic. The toxic products of sulphur hexafluoride may cause severe eye injuries, immediate choking, or coughing; death can occur in a matter of minutes. This gas is usually purified through a charcoal filtering device.

### Battery Acids

The most common battery acid you are associated with is sulphuric acid. Sulphuric acid is basically a corrosive toxic agent;

repeated or prolonged inhalation of its fumes can cause inflammation of the upper respiratory tract, leading to chronic bronchitis. Loss of consciousness with severe damage to the lungs may result from inhalation of concentrated vapors when the sulphuric acid is hot. The acid in a highly concentrated form, prior to adding water for battery use, acts as a powerful caustic, destroying skin and other flesh tissues. This destruction appears as severe burns, and such exposure may be accompanied by shock and collapse. The fumes from highly concentrated sulphuric acid cause coughing and irritation of the eyes; prolonged exposures may produce a chemical pneumonitis.

### Soldering Materials

The soldering area must be well ventilated to protect operating personnel from inflammable fumes, explosive gas mixtures, and fumes which can cause skin and lung irritations. If a metal, such as lead or zinc, is used as a coating on steel, poisonous fumes may be generated during the soldering process.

The materials used in noncorrosive soldering fluxes are relatively safe, but the alkalies, bases, and acids used in corrosive fluxes range from weak to strong, and may present a toxic hazard. Do not allow fluxes to touch the skin unnecessarily; many materials used in soldering fluxes contain skin irritants. Soldering fluxes spatter when they are heated, and the fumes produced by heating corrosive fluxes are irritating to the skin and lungs. Protect your eyes during the soldering operation to prevent damage due to spatter. After handling fluxes, wash your hands thoroughly before eating or smoking. Most fluxes contain materials which are a health hazard if they reach the stomach.

### Mercury Cells

The explosion of mercury dry cells can injure personnel and damage equipment. Although explosions have occurred in storage, the greatest hazard exists when mercury cells are subjected to excessive heat or short circuit. An explosion can be caused when the cell is heated in excess of 400 degrees Fahrenheit. A short circuit across this type of coil can also cause an explosion.

Mercury cells generate hydrogen gas toward the end of their useful life. In the steel-jacketed cell, the hydrogen can build up considerable pressure. An explosion will occur if this compressed hydrogen gas is subjected to sufficient heat or to a spark. This dangerous condition is most likely to occur in a multi-cell battery where one or more individual cells may be weaker than the rest. Five recommended precautions are as follows:

1. Never discharge a mercury-cell battery after its terminal voltage drops to 70 percent of its nominal voltage, or when it fails to operate the equipment in which it is used, whichever occurs first.

2. Never place a direct short across a mercury-cell battery.

3. Never store the equipment with a mercury cell in it.

4. Discard dead mercury-cell batteries as soon as possible.

5. Store spare mercury-cell batteries in a cool, adequately ventilated area.

# SAVE A LIFE

If you observe an accident involving electrical shock,
DON'T JUST STAND THERE - DO SOMETHING!

## RESCUE OF SHOCK VICTIM

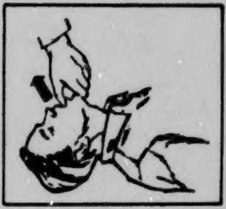
The victim of electrical shock is dependent upon you to give him prompt first aid. Observe these precautions:

1. Shut off the high voltage.
2. If the high voltage cannot be turned off without delay, free the victim from the live conductor. REMEMBER:
   - a. Protect yourself with dry insulating material.
   - b. Use a dry board, your belt, dry clothing, or other non-conducting material to free the victim. When possible PUSH - DO NOT PULL the victim free of the high voltage source.
   - c. DO NOT touch the victim with your bare hands until the high voltage circuit is broken.

## FIRST AID

The two most likely results of electrical shock are: bodily injury from falling, and cessation of breathing. While doctors and pulmotors are being sent for, DO THESE THINGS:

1. Control bleeding by use of pressure or a tourniquet.
2. Begin IMMEDIATELY to use artificial respiration if the victim is not breathing or is breathing poorly:
   - a. Turn the victim on his back.
   - b. Clean the mouth, nose, and throat. (If they appear clean, start artificial respiration immediately. If foreign matter is present, wipe it away quickly with a cloth or your fingers).



   - c. Place the victim's head in the "sword-swallowing" position. (Place the head as far back as possible so that the front of the neck is stretched).
   - d. Hold the lower jaw up. (Insert your thumb between the victim's teeth at the midline - pull the lower jaw forcefully outward so that the lower teeth are further forward than the upper teeth. Hold the jaw in this position as long as the victim is unconscious).
   - e. Close the victim's nose. (Compress the nose between your thumb and forefinger).
   - f. Blow air into the victim's lungs. (Take a deep breath and cover the victim's open mouth with your open mouth, making the contact air-tight. Blow until the chest rises. If the chest does not rise when you blow, improve the position of the victim's air passageway, and blow more forcefully. Blow forcefully into adults, and gently into children.
   - g. Let air out of the victim's lungs. (After the chest rises, quickly separate lip contact with the victim allowing him to exhale).
   - h. Repeat steps f. and g. at the rate of 12 to 20 times per minute. Continue rhythmically without interruption until the victim starts breathing or is pronounced dead. (A smooth rhythm is desirable, but split-second timing is not essential).

DON'T JUST STAND THERE - DO SOMETHING!

ATC HO 3AQR3X020-X
Prepared by Keesler TTC
KEP-HO-108

Technical Training

# TEST EQUIPMENT OPERATING INSTRUCTIONS

1 December 1975

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 6-2804

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

Student Handout 3AQR3X020-X
KEP-HO-108
1 December 1975

# TEST EQUIPMENT
# OPERATING INSTRUCTIONS

This handout contains the operation instructions for test equipment you will use during basic principles training, Course 3AQR3X020-X. These instructions were extracted from the identified technical orders. This training publication is designed for principles training purposes only; whereas the complete TO should always be used as a basic for job performance in the field.

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Supersedes KEP-HO-108, 1 July 1972. All previous editions are obsolete.

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# TECHNICAL MANUAL
(EXTRACT)

## OPERATION

## MULTIMETER AN/PSM-6, AN/PSM-6A, AN/PSM-6B

# SECTION I
# DESCRIPTION

## 1-1. INTRODUCTION.

## 1-2. GENERAL.

1-3. This technical manual comprises the operating instructions for the following multimeters manufactured by Bruno-New York Industries Corporation, New York, New York.

a. AN/PSM-6, part number 56-5002A (figure 1-2) as modified by TCTO 33A1-12-2-507 (serial numbers below 25298)
b. AN/PSM-6, part number 56-5002B (figure 1-1)
c. AN/PSM-6A, part number 165-5002 (figure 1-3) as modified by TCTO 33A1-12-2-510
d. AN/PSM-6B, part number 199-5002 (figure 1-3).

## 1-4. RELATED PUBLICATIONS.

| | |
|---|---|
| T.O.33A1-12-2-2 | Technical Manual, Service, MULTIMETER AN/PSM-6, AN/PSM-6A, AN/PSM-6B |
| T.O. 33A1-12-2-4 | Technical Manual, Illustrated Parts Breakdown, MULTIMETER AN/PSM-6, AN/PSM-6A, AN/PSM-6B |

## 1-5. PURPOSE.

1-6. Multimeters AN/PSM-6, AN/PSM-6A, and AN/PSM-6B are items of general purpose test equipment designed to measure dc and ac voltage, dc current, and resistance in the ranges most commonly encountered in electrical equipment. The maximum values which can be measured are as follows:

a. DC voltage - 5000 volts
b. AC voltage - 1000 volts
c. DC current - 10 amperes
d. Resistance - 10 megohms.

## 1-7. DESCRIPTION.

## 1-8. MULTIMETER AN/PSM-6.

1-9. Multimeter AN/PSM-6 consists of the following items in one completely self-contained case:

a. Multimeter ME-70/PSM-6 or ME-70A/PSM-6
b. Multirange Instrument Shunt MX-1409/U
c. Test Prod MX-1410/U
d. Test Adapter MX-1411/U
e. Test Lead Set CX-2140/U or CX-2140A/U.

## 1-10. MULTIMETER AN/PSM-6A.

1-11. Multimeter AN/PSM-6A consists of the following items in one completely self-contained case:

a. Multimeter ME-70B/PSM-6A
b. Multirange Instrument Shunt MX-1409/U
c. Test Prod MX-1410/U
d. Test Adapter MX-1411/U
e. Test Lead Set CX-2140A/U.

## 1-12. MULTIMETER AN/PSM-6B.

1-13. Multimeter AN/PSM-6B consists of the following items in one completely self-contained case:

a. Multimeter ME-70C/PSM-6B
b. Multirange Instrument Shunt MX-1409/U
c. Test Prod MX-1410/U
d. Test Adapter MX-1411/U
e. Test Lead Set CX-2140A/U.

## 1-14. MULTIMETER ME-70/PSM-6 OR ME-70A/PSM-6.

1-15. Multimeter ME-70/PSM-6 or ME-70A/PSM-6 is the basic instrument for the AN/PSM-6. It consists of a 50-microampere dc meter mounted on an aluminum panel and connected through two multiple switches to precision resistor circuits. All measurements are made with the test leads connected to the two jacks at the bottom center of the multimeter panel and the RANGE and FUNCTION switches set to the desired values. The multimeter is watertight with the cover off. The overall size of the equipment is 8 x 6-3/8 x 4-1/2 inches and the total weight is 7 pounds, 7 ounces. The minimum accuracies attained are printed on the lid of the multimeter cover. At room temperatures, the accuracy of measurement is within ±3 percent on all dc ranges and ±4 percent on all ac ranges except the 0.5 volt range, which is influenced by source impedance.

## 1-16. MULTIMETER ME-70B/PSM-6A.

1-17. Multimeter ME-70B/PSM-6A is the basic instrument for the AN/PSM-6A. It is the same as models ME-70/PSM-6 and ME-70A/PSM-6 with the exception of having a pulsed dc current function instead of an output function. This makes it possible to measure pulsating dc currents having high peak values, and average values up to 1 ampere. Such currents cannot be measured accurately with the AN/PSM-6. The overload protective system in the ME-70B/PSM-6A was disabled by Safety Supplement

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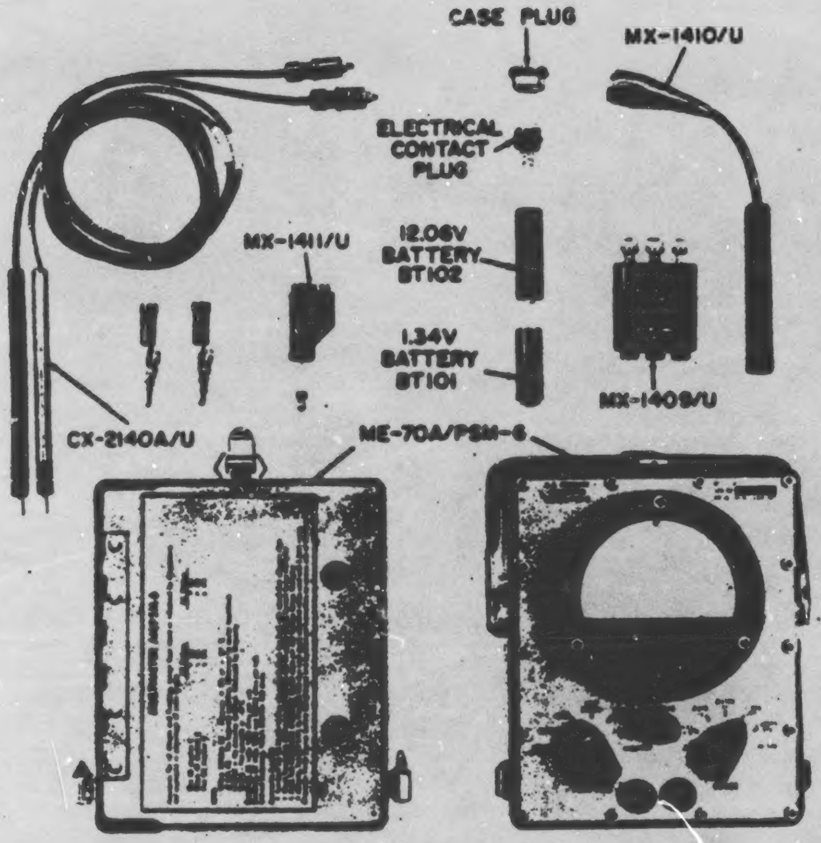


*Figure 1-1. Multimeter AN/PSM-6 Using Multimeter ME-70A/PSM-6*

T.O. 33A1-12-2-SS-2-1 and TCTO 33A1-12-2-510. This modification was accomplished to eliminate a potential safety hazard that existed when the meter protection relay was tripped. High voltage could be present even though the meter indicated zero voltage and no overload indication was present.

## 1-18. MULTIMETER ME-70C/PSM-6B.

1-19. Multimeter ME-70C/PSM-6B is the basic instrument for the AN/PSM-6B. It is the same as model ME-70B/PSM-6A with the exception of having the overload protective system operative. This system is incorporated to protect the instrument against damage due to incorrect settings of the RANGE or FUNCTION switch or incorrect polarity of test lead connection. An integral OVERLOAD RESET button is provided to restore normal operation. This system is capable of protecting every RANGE-FUNCTION combination under the following maximum conditions:

a. From a power source having 2000 volts open circuit, capable of delivering a maximum short-circuit current of 375 ma and a maximum surge current of 30 amperes which decays to 400 ma within 2 milliseconds:

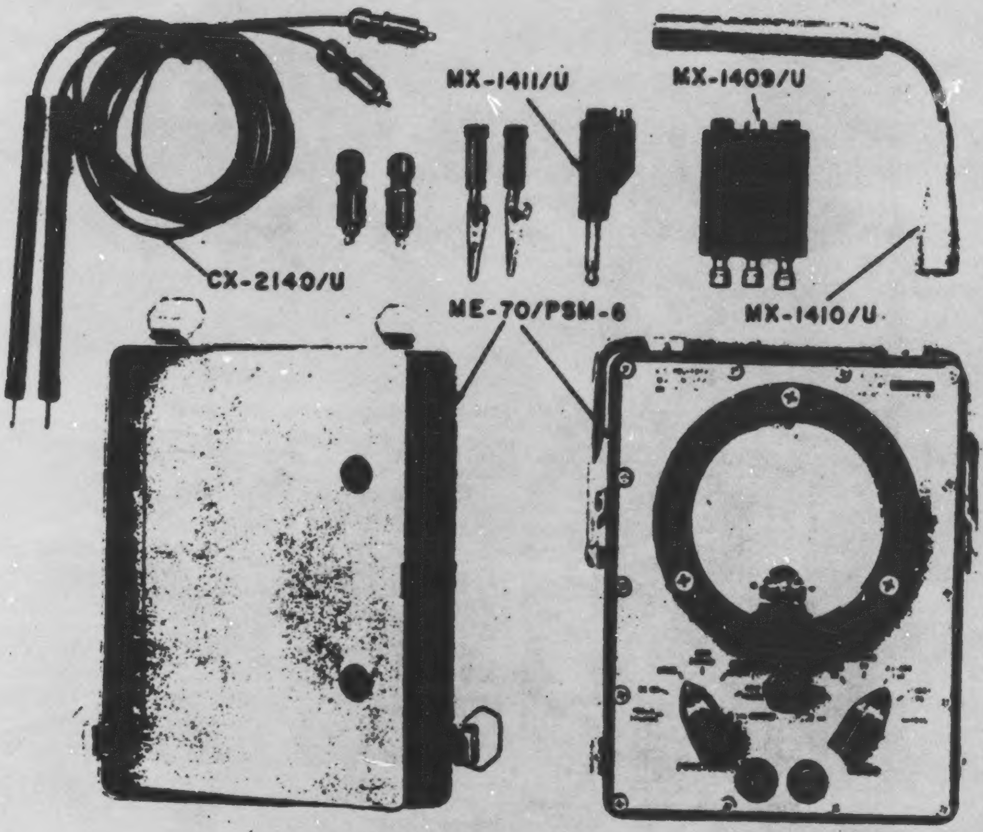


*Figure 1-2. Multimeter AN/PSM-6 Using Multimeter ME-70/PSM-6*

(1) 2000 volts dc applied in the forward direction

(2) 2000 volts dc applied in the reverse direction

(3) 2000 volts ac at 60 cps.

b. From a power source not requiring the multimeter to dissipate more than 750 watts of power in any current range:

(1) 10 amperes dc applied in the forward direction

(2) 10 amperes dc applied in the reverse direction

(3) 10 amperes ac at 60 cps.

**NOTE**

Because of the variability among identical components with respect to their ability to withstand peak overload voltages and currents, the number of overloads for which any individual multimeter is protected will vary from unit to unit.

1-20. HANDLE.

1-21. The multimeter handle has been designed to serve a dual function. In addition to carrying or suspending the multimeter, the handle may be folded back and locked into the pins projecting from the case, as shown at the left of figure 1-4, to form an easel support which holds the instrument at a 30-degree angle so that it may be used more conveniently on a bench or table. To lock the handle in its stowed position, fold it over the top of the case, as shown at the right of figure 1-4, and pull forward the bottom of the handle hinges until a positive lock is obtained. To unlock, push the bottom of the hinge toward the back of the instrument.

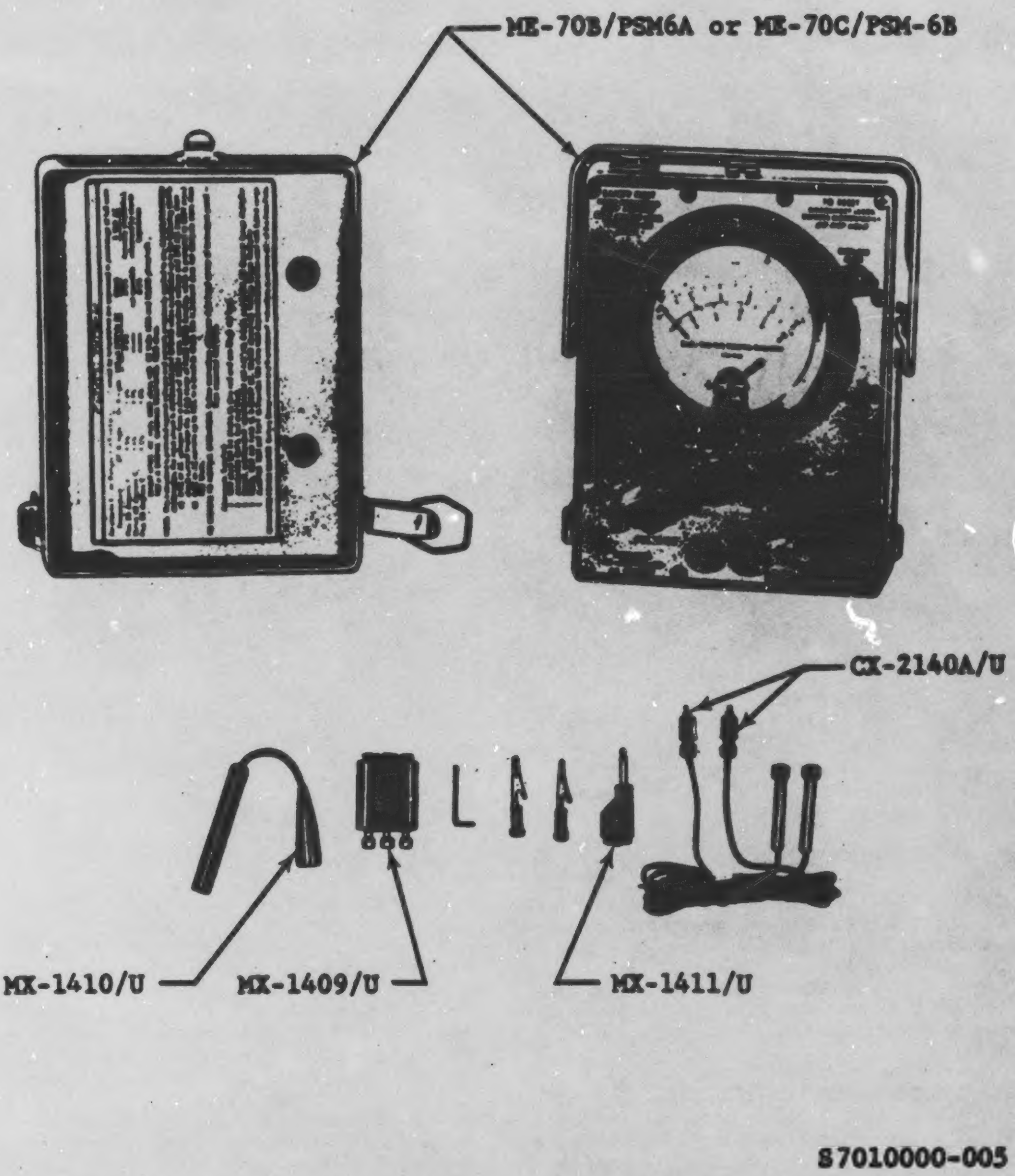
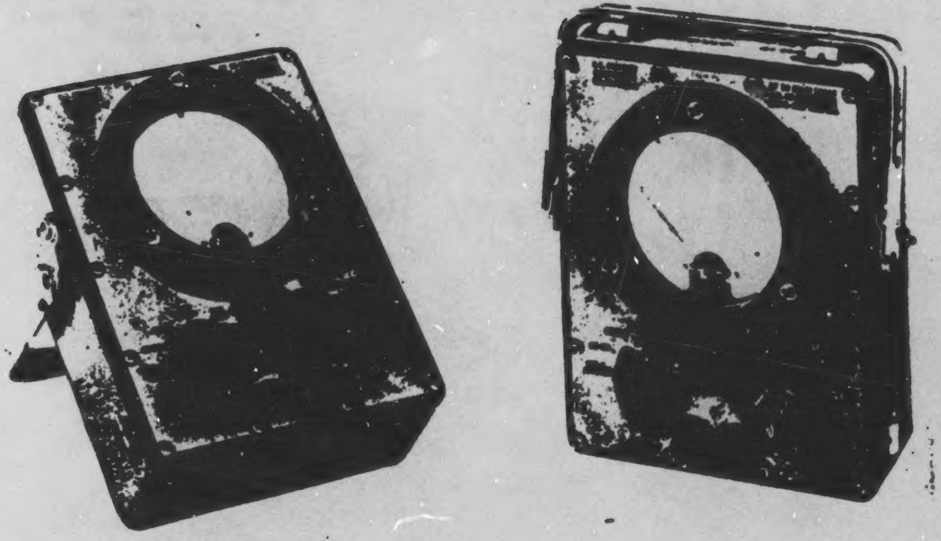


*Figure 1-3. Multimeter AN/PSM-6A Using Multimeter ME-70B/PSM-6A or Multimeter AN/PSM-6B Using Multimeter ME-70C/PSM-6B*

### 1-22. MULTIRANGE INSTRUMENT SHUNT MX-1409/U.

1-23. This shunt is supplied to extend the current-measuring range of the multimeter to a maximum of 10 amperes. It consists of two low-resistance shunt sections within a plastic case, to be used either for the 0 to 2.5 ampere or 0 to 10 ampere range. The shunt, together with the other items described below, is stowed in a compartment under the cover lid when not in use.


EASEL POSITION

STOWED POSITION

*Figure 1-4. Handle Positions*

1-24. TEST PROD MX-1410/U.

1-25. This test prod is an external high-voltage multiplier which extends the dc voltage range of the equipment to 5000 volts. It is used only with the 20,000 ohms/volt dc scale. The prod casing is constructed of plastic with a high voltage breakdown rating, but it is not designed to be connected or disconnected while the source of high voltage is turned on.

1-26. TEST ADAPTER MX-1411/U.

1-27. Standard crystal current measurements require a 100-ohm impedance at the terminals of the meter circuit. The test adapter is designed to adapt a phone plug output to the test leads of the multimeter, and contains a built-in resistor to provide a total meter impedance of 100 ohms with the adapter in use.

1-28. TEST LEAD SET CX-2140/U OR CX-2140A/U.

1-29. Four feet of cable is used to couple the circuit under test to the multimeter. The plugs which connect into the meter jacks are of the interlock type. To connect plug to the multimeter, slide the front part of the plug backwards and insert the plug into the jack. The plug will lock automatically and cannot be disengaged until the rear portion is slid forward to meet the front portion again. Two detachable alligator clips are furnished with the multimeter for use as desired. A pair of spare plugs is also supplied with multimeters having serial numbers below 25296. Instructions for the assembly of plugs to the leads, and also for the repair of broken leads are provided in the Service Manual for this equipment.

## SECTION II

## PREPARATION FOR USE

2-1. GENERAL.

2-2. This section is not applicable. Refer to the applicable section in the Service Manual.

## SECTION III

## OPERATION

3-1. OPERATING CONTROLS.

3-2. FUNCTION SWITCH. (See figures 3-1 and 3-2.)

3-3. The FUNCTION switch is located at the lower left of the multimeter panel and provides the means for setting the instrument for the particular electrical characteristic to be measured.

3-4. RANGE SWITCH. (See figures 3-1 and 3-2.)

3-5. The RANGE switch is located at the lower right of the panel. Once the FUNCTION switch has been set, the correct instrument range to provide an accurate scale indication is set with the RANGE switch.

3-6. OHMS ZERO. (See figures 3-1 and 3-2.)

3-7. The OHMS ZERO control is located directly below the meter on the panel, and is used only in resistance measurements to zero the meter for changes in range or battery voltage.

3-8. OVERLOAD RESET BUTTON (AN/PSM-6A AND AN/PSM-6B ONLY). (See figure 3-2.)

3-9. The OVERLOAD RESET button is inoperative in the AN/PSM-6A. Refer to MULTIMETER ME-70B/PSM-6A (Section I). The OVERLOAD RESET

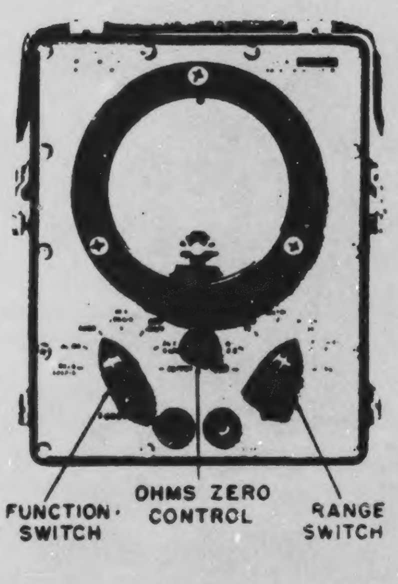


*Figure 3-1. AN/PSM-6 Operating Controls*

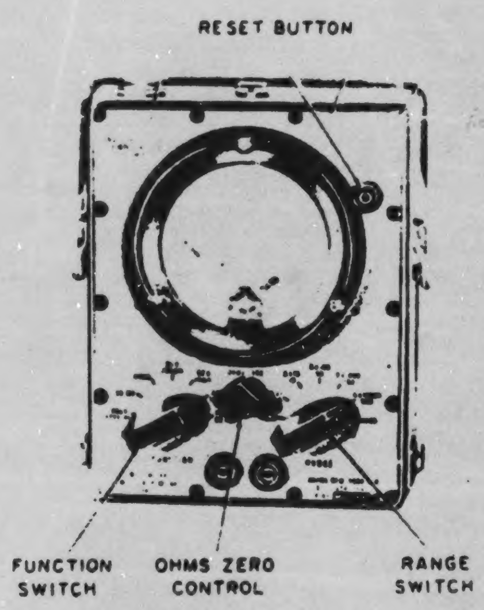


*Figure 3-2. AN/PSM-6A or AN/PSM-6B Operating Controls*

button on the AN/PSM-6B indicates red when an overload has occurred. The overload protective system is reactivated by disconnecting the test leads from the circuit under test and depressing the OVERLOAD RESET button so that the red indication disappears.

**CAUTION**

Do not hold the OVERLOAD RESET button during an overload condition with the test leads connected.

### 3-10. OPERATING PROCEDURES.

### 3-11. PRELIMINARY.

3-12. If the instrument has never been used before, a battery voltage check may be made as follows:

a. Set the FUNCTION switch at OHMS and the RANGE switch at X1.
b. Plug the test leads into the meter jacks and short-circuit the test lead tips together.
c. Adjust OHMS ZERO knob until the meter pointer is exactly at zero on the OHMS scale.
d. Repeat step c with RANGE switch set at X10, X100, X1000, and X10,000, respectively. If pointer cannot be zeroed on all ranges, the battery voltage is low. Instructions for replacing the battery are found in the Service Manual.

WARNING – Deleted

### 3-13. DC VOLTAGE MEASUREMENTS.

3-14. DC voltages may be measured in the range of 0 to 1000 volts at a sensitivity of either 1000 ohms/volt or a sensitivity of 20,000 ohms/volt. The use of Test Prod MX-1410/U permits voltage measurements up to 5000 volts at a sensitivity of 20,000 ohms/volt only. To measure dc voltages in the range of 0 to 1000 volts, the procedure is as follows:

a. Set FUNCTION switch at DCV-20K Ω/V or DCV-1K Ω/V as desired.
b. Set RANGE switch to desired range.

**CAUTION**

Whenever taking any unknown voltage or current measurement, always set RANGE switch to highest range first and then decrease until the appropriate range is reached. Failure to observe this precaution may result in overload and possible damage to the meter or circuit components.

c. Plug test leads into meter jacks.
d. Place the test lead tip at the points between which the voltage is to be measured, with the red lead connected to the positive side. If the meter deflects backwards, reverse test lead connections.

### 3-15. HIGH DC VOLTAGES (to 5000V DC, 20,000 ohms/volts only).

3-16. For voltages between 1000 and 5000 volts dc, Test Prod MX-1410/U must be used. The procedure is as follows:
a. Set FUNCTION switch at DCV-20K Ω/V.
b. Set RANGE switch at 500.
c. Plug test leads into meter jacks.
d. Plug tip of red test lead into pin jack end of test prod for positive voltage. Plug tip of black test lead into pin jack end of test prod for negative voltage.

**WARNING**

Be sure equipment under test is turned off before attempting to connect test prod or test leads.

Do not turn on until test leads are clipped into place.

e. Connect the clip of the high voltage test prod to the positive side of the source for positive measurements, or to the negative side of the source for negative measurements. Attach an alligator clip to the remaining test lead tip and connect it to the other side of the voltage source, observing polarity.

f. Turn on high voltage. Read on meter. Full scale deflection corresponds to 5000 volts.

### 3-17. AC VOLTAGE MEASUREMENTS.

3-18. AC voltage may be measured in the range of 0 to 1000 volts at a sensitivity of 1000 ohms/volt. The procedure is as follows:

a. Set FUNCTION switch to ACV-1K Ω/V and RANGE switch to desired range.
b. Plug test leads into meter jacks.
c. Connect test lead tips to circuit being measured.

**NOTE**

The internal rectifier in the multimeter is designed to operate at frequencies up to approximately 1000 cycles per second. Measurements made at higher frequencies will, therefore, suffer in accuracy.

### 3-19. OUTPUT MEASUREMENTS (AN/PSM-6 ONLY).

3-20. The procedure for making output voltage measurements is identical to that for ac voltage except that the FUNCTION switch is set at OUTPUT. In this position, a one-microfarad capacitor is placed in series with one test lead so that any dc component of the voltage being measured is blocked out. Since the impedance of this capacitor varies with frequency, the accuracy of any output voltage measured will depend upon its frequency.

**CAUTION**

Any ac voltage with a dc component above 200 volts will damage this capacitor. For such measurements, use ac setting and suitable external series capacitor.

## 3-21. PULSE DC MA (AN/PSM-6A AND AN/PSM-6B ONLY).

3-22. The procedure for making pulsed dc current measurements is identical to that for DC CURRENT MEASUREMENTS except that the FUNCTION switch is set at PULSE DC MA.

## 3-23. DC CURRENT MEASUREMENTS.

3-24. DC currents from 0 to 1 ampere may be measured directly on the multimeter, and currents up to 10 amperes may be measured with the use of Instrument Shunt MX-1409/U. The procedure is as follows:

a. Set FUNCTION switch to DC MA.
b. For measurements up to 1 ampere, set RANGE switch at desired range.
c. Plug test leads into meter jacks. Connect other end of leads in series with circuit under test while the power is off. Turn on power and read meter.
d. For measurements above 1 ampere, connect test lead tips to ± and 2.5A pin jacks or ± and 10A pin jacks (as desired) on shunt. Connect circuit under test to corresponding load circuit binding posts. The RANGE switch is set at 2.5 or 10 as required.

**NOTE**

Excessive contact resistance on the load circuit side will reduce the measurement accuracy considerably. Care should be exercised to keep this resistance at a minimum.

e. Turn on power and read meter. For a RANGE switch setting of 2.5, full-scale deflection corresponds to 2.5 amperes and for a RANGE switch setting of 10, full-scale deflection corresponds to 10 amperes.

## 3-25. RESISTANCE MEASUREMENTS.

3-26. To measure resistance from 0 to 10 megohms, the procedure is as follows:

a. Set FUNCTION switch at OHMS.
b. Set RANGE switch at proper multiplier so that estimated value of resistor to be measured will fall in the right hand portion of the ohmmeter scale.
c. Plug test leads into meter jacks.
d. Short circuit the free ends of the test leads.
e. Adjust OHMS ZERO control until meter pointer reads zero on the OHMS scale. This adjustment should be repeated each time the RANGE switch setting is changed to obtain maximum accuracy of measurement.
f. Clip the test lead ends across the resistance to be measured. Read resistance on OHMS scale.

## 3-27. 100-MICROAMPERE SPECIAL.

3-28. With the FUNCTION switch set at 100 μ A SPECIAL and the RANGE switch in any position, the multimeter becomes a 0 to 100 microampere dc microammeter measuring the current in series with the test leads.

## 3-29. CRYSTAL CURRENT MEASUREMENTS.

3-30. To make standard measurement of crystal current, Test Adapter MX-1411/U is used as follows:

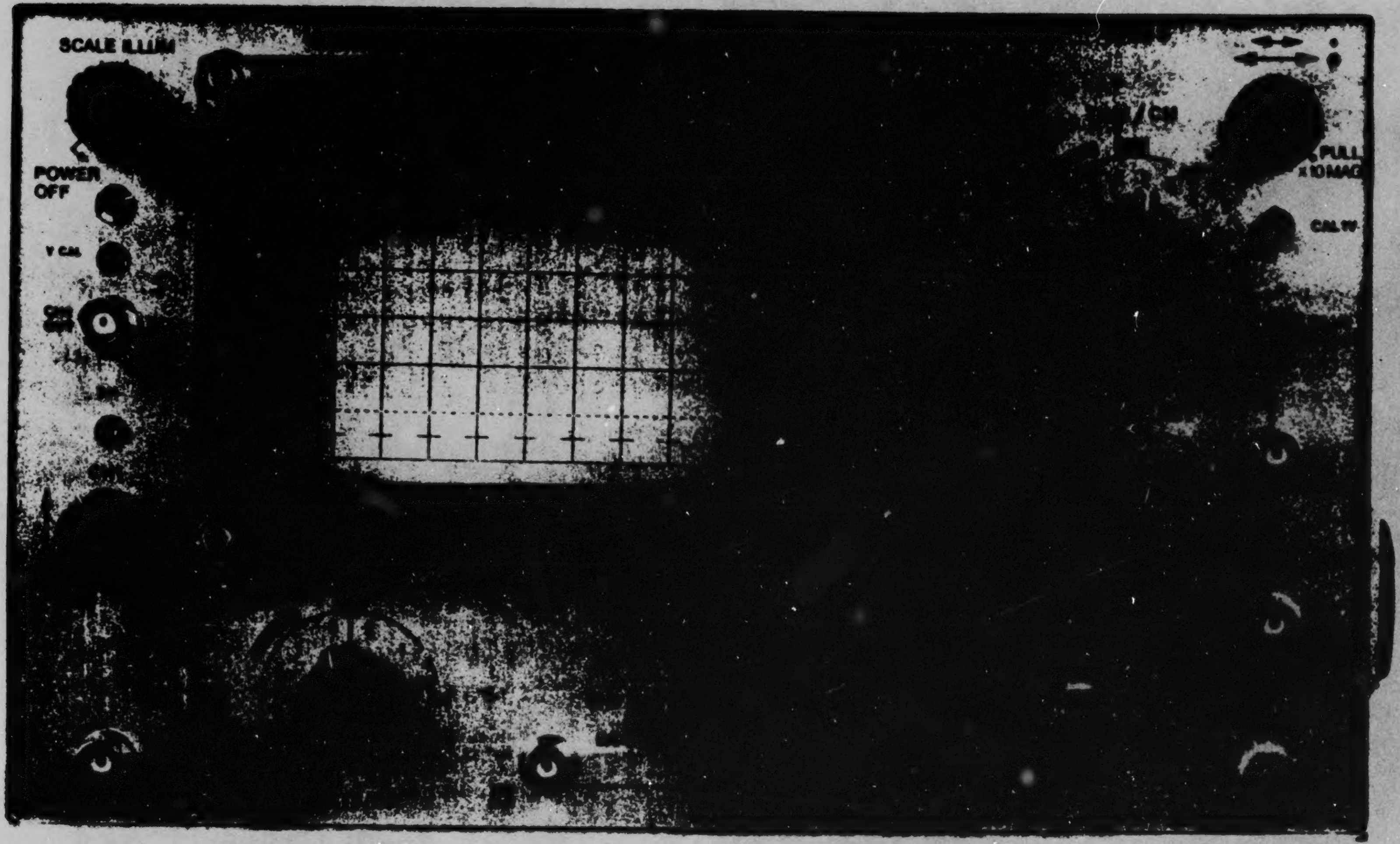
a. Set FUNCTION switch to DC MA.
b. Set RANGE switch to 2.5.
c. Plug test leads into meter jacks and connect test lead tips to pin jacks on adapter.
d. Connect phone plug to test circuit and read current on 2.5 milliampere scale.

T. O. 33A1-13-451-1

# TECHNICAL ORDER
# (EXTRACT)

## OPERATING INSTRUCTIONS

## OSCILLOSCOPE, AN/USM 398
## (BALLENTINE 10665)



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# SECTION IV

## OPERATION INSTRUCTIONS

4-1. GENERAL.

4-2. This section contains theory of operation and operation instructions for the AN/USM-398. Detailed test procedures are contained in Section V.

4-3. THEORY OF OPERATION.

4-4. The theory of operation for the AN/USM-398 is covered by a block diagram (figure 4-1) and by functional diagrams (figures 4-2 and 4-3). The associated descriptions are contained in the paragraphs which follow.

4-5. CHANNEL 1 AND 2 Y INPUT ROUTING. (See figure 4-1.) The CH1 and CH2 Y input signals are applied to corresponding attenuators, either directly or through the voltage divider probe supplied with the probe kit. Use of the probe does not load the circuit under test but does divide the input voltage by a 10 to 1 ratio. The attenuators provide additional signal attenuation, coupling selection, attenuator compensation, and input capacitance adjustments. The output of each attenuator is applied to a balanced two-FET input amplifier which provides a signal gain of unity and a high input impedance. The step attenuator balance adjustment is performed in the input amplifier.

4-6. Separate preamplifiers for each channel provide the gain required to drive the Y output amplifier through the channel switch, buffer amplifier, and delay line. By means of balanced bifilar cable delay line DL1, the input signals are delayed 150 ns to allow the timebase circuits sufficient time to respond to internal trigger signals and permit display of the entire input signal on the CRT screen. The CH2 preamplifier includes a reversing switch designated PULL TO INVERT CH2, which permits a reversal of CH2 display polarity. The CH2 input is also routed to the CH2 output amplifier before reaching the channel switch. This provides an output of the CH2 signal at front panel connector J5.

4-7. DISPLAY CONTROL. The AN/USM-398 is capable of operation in three vertical modes. These are listed below, along with their variations.

1. Single-trace mode, displaying either of the following:

   a. CH1 only, in the normal polarity (positive signals deflect up on the CRT)

   b. CH2 only, in either normal or inverted polarity (depending on the setting of the PULL TO INVERT CH2 switch)

2. Dual-trace mode, displaying both channels at once in either of the two following forms:

   a. CH1 with CH2 normal (positive up)

   b. CH1 with CH2 inverted (negative up)

Channel switching between the two channels may take place either synchronously, with alternate sweeps, or asynchronously, at a 400-kHz chop rate.

3. Added (CH1 & CH2) mode, in which the two channels are combined algebraically to produce a single trace display representing either of the following:

   a. CH1 + CH2

   b. CH1 - CH2

4-8. These three display options are available with the X deflection controlled either by the internal timebase circuits (TIME/CM switch positions .5 uS through 1 SEC) or by an external source (TIME/CM switch positions EXT X and X-Y). The selection of which channel information is to be displayed on the CRT at any given time (CH1 and/or CH2) is determined by the CH1 and CH2 steering inputs developed by the channel switch multivibrator (MV). When active, each of these steering inputs causes the signal from the associated channel to pass through the channel switch and be applied to the buffer amplifier. In producing the steering inputs, the channel switch MV is programmed by the CH1 and CH2 selector switches (which are ganged with the respective position controls), the TIME/CM timebase switch, the SEPARATE - CH1 & CH2 mode switch, and the channel switching pulses provided by the chop MV. As noted in the preceding paragraph, channel switching can occur either synchronously, alternating with successive sweeps (alternating mode), or asynchronously, with the chop MV free-running at 400 kHz (chop mode). This selection of the mode at channel switching is available for all dual-trace operation, whether horizontal deflection is controlled internally or externally. For most purposes, the alternate mode of channel switching is used. The chop mode is used only to prevent flicker in the display. Consequently, use of the chop mode should be restricted to TIME/CM switch settings of 1 mS through 1 SEC.

4-9. The channel switch MV selects CH1 and/or CH2 in one of the four following modes:

1. In the single trace mode, the channel switch MV is held in either the set or reset state, causing either CH1 or CH2 to be selected continuously.

2. In the dual trace mode, the channel switch MV is made bistable, causing the channel selection to switch from one channel to the other as each channel switching pulse is received from the chop MV. As stated previously, channel switching can occur either asynchronously, at the 400-kHz chop rate, or synchronously, at the sweep rate.

3. In the combined or CH1 & CH2 mode, both CH1 and CH2 are made continuously active. The CH1 and CH2 information is thus added or subtracted (depending on the PULL TO INVERT CH2 switch position) and displayed as a single trace.

4. In the X-Y mode, as in the single-trace mode for CH2, CH2 is selected continuously while the selection of CH1 is locked out. In this mode, only CH2 supplies Y deflection information while CH1 is used in place of the sweep circuits to develop the X signal for the X output amplifier.

4-10. As noted in the preceding paragraph, channel switching, during dual-trace operation, is initiated by channel switching pulses produced by the chop MV. The chop MV also provides chop blanking pulses which blank out the CRT beam while it is moving between the two traces. In producing the channel switching and chop blanking pulses, the chop MV is programmed by the CH1 and CH2 selector switches (ganged with the vertical position controls), the TIME/CM timebase switch, the ALT-CHOP mode switch, and the end of the sweep gate pulses from the timebase MV. The chop MV generates channel switching and chop blanking pulses in one of the two following basic modes:

1. In the alternate mode, the chop MV is made monostable, causing one channel switching/chop blanking pulse to be generated with each end of sweep gate pulse received from the timebase MV at the end of the sweep. This causes the switching of channels to be synchronized with the end of each sweep.

2. In the chop mode, the chop MV is made free-running, causing channel switching/chop blanking pulses to be generated asynchronously at a nominal 400-kHz rate.

4-11. Single-Trace Mode. With the SEPARATE - CH1 & CH2 switch in the SEPARATE position, the TIME/CM switch in any but the X-Y position, and with one (and only one) of the CH1 and CH2 selector switches set to its active position (i.e., off the OFF detent), selection of the associated channel is unlocked in the channel switch MV. The other channel remains locked in the unselected (OFF) position. This prevents the switching of channels by the channel switching pulses from the chop MV. Although neither channel switching nor chop blanking pulses are required for single-trace operation, the chop MV is caused to operate in the alternate mode by the enable alternate mode input produced when one of the CH1, CH2 selector switches is in the OFF position. As previously noted, the channel switching pulses from the chop MV have no effect on the channel switch MV when the latter is in single-trace mode. Furthermore, since only one channel is involved, the chop blanking pulses in this mode simply reinforce the sweep retrace blanking on the CRT.

4-12. Dual-Trace Mode. With all switches set as previously described but with both the CH1 and CH2 selector switches set to their active positions (i.e., neither switch in the OFF detent), the selection of both channels is unlocked. However, since the channel switch MV operates as a bistable device in this mode, only one of the two channels will actually be selected at any given instant. The selection alternates with each channel switching pulse received from the chop MV. In this dual trace mode, channel switching and chop blanking occur as specified by the positioning of the CHOP-ALT switch, except when the TIME/CM switch is in the EXT X position. In this position, the sweep circuits are not triggered, the horizontal (X) deflection of the display being controlled by an external source. The resulting absence of the end of sweep pulses makes alternate operation of the chop MV impossible and the free-running or chop mode must be forced. This is done by interrupting the -15-volt supply to the CHOP-ALT switch when the TIME/CM switch is in the EXT X position.

4-13. Added (CH1 & CH2) Mode. Switching the SEPARATE - CH1 & CH2 switch to the CH1 & CH2 position while retaining all other switch settings will force both the CH1 & CH2 outputs of the channel switch MV to become active together, thus selecting both channels simultaneously. As noted before, the result of this dual channel selection is a continuous summing, in the buffer amplifier, of the input amplitude of CH1 with either the normal or inverted signal input amplitude of CH2. As previously noted, this CH2 polarity is under control of the PULL TO INVERT CH2 switch. The output from the CH1 & CH2 position of the SEPARATE - CH1 & CH2 switch is also applied to the chop MV to force alternate operation. Thus, in this mode (as in the single trace mode) the chop blanking reinforces the timebase retrace blanking of the CRT.

4-14. X-Y Mode. With both channels unlocked by the CH1 and CH2 selector switches and with the SEPARATE - CH1 & CH2 switch returned to the SEPARATE position, setting the TIME/CM switch to its X-Y position will force a selection of CH2 for the Y input, while locking out the selection of CH1. In this mode, CH1 is used to supply the X input. Since this mode uses only a single trace, neither channel switching nor chop blanking pulses are required. Consequently, the chop MV is left idle. The -15-volt supply routed through the X-Y position of the TIME/CM switch prevents chop operation by forcing alternate operation. However, alternate operation does not occur since, in the absence of a trigger input, no end of sweep pulses are present.

4-15. Detailed Circuit Operation. (See figure 4-2.) The detailed circuit operation of the display control circuits is given in the following paragraphs. These descriptions consider as separate entities the chop MV, the channel switch MV, and the channel switch.

4-16. The chop MV contains transistors Q401 and Q402. In the chop mode, these operate as an emitter coupled astable MV whose frequency of 400 kHz is determined by the values of capacitor C406 and resistors R405 and R412. The circuit acts as a monostable MV when the alternate mode of channel switching is used. In the alternate mode, the circuit produces one pulse per timebase sweep as initiated by the end of sweep gate pulse.

4-17. When, during one of the operating modes described in the preceding paragraphs, the chop MV is put into the alternate mode, a -15-volt signal is supplied to the chop MV by one of the switch position combinations associated with the active mode. This -15-volt level coupled through resistor R406 increases current through transistor Q401 and cuts off transistor Q402. The emitter of transistor Q402 is prevented from going as negative as the base by diode CR401 which is reduced to a fixed voltage determined by resistors R410 and R411. The negative-going end of sweep gate pulse thus finds the circuit in a monostable condition which it triggers and produces a high amplitude pulse at the collector of transistor Q402. This pulse is nominally less than 1 us in duration and is used to trigger the channel switch MV and blank the CRT trace while the channel switch is dynamically active. Two outputs are taken from the collector of transistor Q402. One is routed as a chop blanking pulse to the CRT. The other is attenuated by resistor R409 and then fed as drive to the channel switch MV.

4-18. The channel switch MV circuit contains transistors Q407 and Q408 which, in the dual-trace mode, produce a ÷ 2 function when driven by the channel switching pulses from the chop MV. The input trigger from the chop MV is steered to the respective base by diodes CR403 and CR405.

4-19. The ÷ 2 operation is a function of the settings of the CH1 and CH2 selector switches. For dual trace operation, neither the CH1 nor CH2 switch may be at the OFF setting and input resistors R452 and R454 of the channel switch MV are connected via the selector switch (ganged with each CH1, CH2 position control) to -15 volts. As a result, diodes CR402 and CR406 are cut off and the circuit is unlocked, allowing it to operate in the ÷ 2 bistable mode.

4-20. If the CH1 selector on the position control is set to OFF, the -15 volts is disconnected and current flows into the base of transistor Q407 via resistor R429 and diode CR402. This locks the channel switch MV and biases it into the condition required for single trace CH2 operation. The circuit is similarly locked and biased if the CH2 selector switch is set to OFF with the collectors of transistors Q407 and Q408 (which steer the respective channel switches) at opposite levels from those found in CH1 OFF mode.

4-21. If both CH1 and CH2 selector switches are set to OFF, diodes CR404, CR407, and CR220 and resistors R322 and R321 apply a positive base bias to transistors Q407 and Q408. This ensures that both channels are locked in the unselected state. In the CH1 & CH2 mode, resistors R459 and R470 are connected to -15 volts. These cut off both transistors Q407 and Q408, which in turn cause the channel switch to switch on both channels simultaneously to provide channel summing. The SEPARATE - CH1 & CH2 switch (S25) also selects the appropriate operating bias for the buffer amplifier.

4-22. The channel switch consists principally of eight diodes CR203 through CR210 and is used to implement the channel selection established by the channel switch MV. When the CH1 steering input from the channel switch MV is positive, diodes CR203 and CR205 are cut off, permitting the passage of the balanced output from the CH1 preamplifier through diodes CR204 and CR206 to the buffer amplifier. When the CH1 steering input is negative, diodes CR203 and CR205 conduct and diodes CR204 and CR206 are cut off, blocking passage of the signal to the buffer amplifier. A similar action occurs in the CH2 section of the channel switch. The passage or blocking of signals by these two channel steering inputs makes possible the display modes described earlier.

4-23. TRIGGER CIRCUITS. (See figure 4-1.) In all timebase positions of the TIME/CM switch (.5 uS through 1 SEC), synchronization of the display is established through use of a trigger signal. This trigger signal is normally derived from either CH1 or from CH1 and CH2. It may also be derived from the line power or an external source. Following processing, the completed trigger signal is used within the sweep circuits to fix the point on the trigger waveform at which each sweep begins.

4-24. Trigger Selection. The type of trigger to be used is selected on TRIG SELECT switch S5. For most operating conditions, one of two internal trigger sources is used. These are represented on the TRIG SELECT switch by the positions designated CH1 (a trigger derived from the CH1 preamplifier) and CH1 & 2 (a trigger derived from the composite CH1 and CH2 information, available at the output of the buffer amplifier). The CH1 & 2 position permits an alternating synchronized display of two signals having different frequency and phase. It may also be used for triggering from CH1 or CH2 when either of these is selected for a single-trace display. In dual-trace displays, use of the CH1 & 2 position of the TRIG SELECT switch must always be accompanied by alternate mode operation of the chop MV. This ensures stable triggering of the timebase by avoiding interference from chop switching transients. These transients are always present in the buffer amplifier when channel switching is being carried out in the chop mode.

4-25. Selection of line or external trigger is not covered at the block diagram level but is described in the detailed circuit operation, paragraph 4-29.

4-26. Trigger Processing. Following amplification and switching, the selected trigger is compared in level with a level established by the setting of LEVEL control R17, established manually by the operator when the control is out of the AUTO detent.

The LEVEL control enables the operator to choose the point on the trigger waveform at which the sweep will begin. This is the point at which the Schmitt trigger, which is used to shape the trigger signal, will fire. When the LEVEL control is turned to the AUTO detent, ganged switch S6 opens and the triggering operation becomes automatic.

4-27. In the AUTO position, the LEVEL control causes a bright trace to be produced when the trigger signal is lost, repeats at less than 40 Hz, or becomes unreliable during AUTO operation. This is done by applying an auto control signal to the bright line auto circuit, which then commands the sweep to free-run at its maximum repetition rate.

4-28. In addition to the trigger sources described in the preceding paragraphs, it is also possible to operate the AN/USM-398 on either an external trigger or on a trigger derived from the line power. These additional options are described in the following paragraph covering detailed circuit operation.

4-29. Detailed Circuit Operation. (See figure 4-3.) The trigger selector switch has 9 settings as follows:

| | |
|---|---|
| LINE | + or - |
| CH1 | + or - |
| CH1 & 2 | + or - |
| EXT | + or - |
| FREE RUN | |

4-30. On TRIG SELECT switch S5A rear, four positions corresponding to the + and - functions of CH1 and CH1 & 2 are utilized to allow a common amplifier for the associated internal trigger signals. This internal trigger amplifier operates in a grounded emitter configuration with negative feedback. The output of the internal trigger amplifier is connected to TRIG SELECT switch S5A front, as is a line trigger, derived from a winding on the power supply transformer, and an external trigger connection, applied from the front-panel EXT TRIG connector J3, via the RC network of R15 and C7. This network attenuates the input level of the external trigger signal to effectively increase trigger LEVEL range for external signals and to permit the safe handling of large amplitude external trigger inputs.

4-31. The wiper of TRIG SELECT switch S5A front connects the selected trigger source to AC-ACF-DC switch S7 on the front panel. At the AC setting of the switch, the trigger signal is capactively coupled via capacitor C230 to the base of emitter follower amplifier Q220. The low frequency cutoff in this position is nominally 50 Hz. At the ACF setting, however, capacitor C9 and resistor R276 function as an RC trigger coupling high-pass filter, which attenuates low frequencies below 50 kHz. In this way, high frequency triggering pulses can be separated from a complex signal having unwanted low frequency components such as power supply hum. Finally, when the DC setting of switch S7 is selected, the trigger signal is coupled directly to emitter follower Q220, which, in turn drives emitter follower Q227. Complete instructions for appropriate use of the AC-ACF-DC switch are contained in paragraph 4-59.

4-32. In the manual position, switch S6A of the LEVEL control causes the output of emitter follower Q227 to be directly coupled to the wiper of TRIG SELECT switch S5B front through zener diodes CR222 and CR225 and through diode CR221. This switch wafer supplies the signal input to the differential amplifier made up of transistors Q222 and Q223, which is a comparator stage. The reference (LEVEL) input is coupled to the comparator through switch wafer S5B rear and bypassed to ground through capacitor C10. In the manual mode, LEVEL switch S6A is closed, causing diode CR222 to conduct and diode CR225 to develop its zener voltage. The cathode of coupling diode CR221 is thus at approximately 3.9 volts with respect to its anode while the zener diode CR225 is conducting in the forward direction. At this voltage, diode CR221 conducts, providing a dc path. In the AUTO mode, LEVEL switch S6A is open, diode CR225 conducts and develops its zener voltage. With approximately +3.9 volts across diode CR225 and with diode CR222 conducting in the normal forward direction, diode CR221 is reverse-biased. The trigger circuit is then ac coupled through capacitor C229 when the LEVEL control is in the AUTO position.

4-33. The front and rear wafers of TRIG SELECT switch S5B provide a means of inverting the trigger signal. For any type of trigger selected (except FREE RUN), two positions are provided: + and -. Each such position pair has reversed connections for the signal and level reference inputs. Thus, the determination is made whether the Schmitt trigger is to fire during a positive or a negative slope of the triggering signal.

4-34. Within the polarity thus selected, LEVEL control potentiometer R17 fixes the point at which the Schmitt trigger fires by comparing the trigger signal to the dc level at the reference input of the differential comparator amplifier. This, in turn, changes the input level applied to the Schmitt trigger and thus causes it to fire earlier or later during the waveform, depending on the direction of the manual adjustment of the LEVEL control.

4-35. The output of the differential comparator amplifier is applied via diode CR215 through both a dc-coupled path (resistors R295 and R296) and an ac-coupled path (capacitor C236). In the manual mode, with LEVEL control switch S6B closed, the dc-coupled path carries the dc level imposed on the differential comparator amplifier output by the setting of LEVEL control potentiometer R17. In the AUTO mode, LEVEL control switch S6B is opened and only capacitive coupling exists between the differential amplifier and the Schmitt trigger. In this condition, the Schmitt trigger becomes astable and will lock onto any trigger signal having a repetition frequency greater than its natural astable frequency of (nominally) 15 Hz.

4-36. **SWEEP CIRCUITS.** (See figure 4-1.) The sweep circuits provide the voltage required to control the horizontal deflection of the CRT beam. The sweep circuits may be operated as a linear timebase in a triggered sweep mode, using either internal or external signals to provide the synchronizing trigger. They may also be operated in an X amplifier mode, in which the X deflection is established by external input signal, just as the Y deflection. The mode of operation is selected principally by means of TIME/CM switch S5, which selects the timebase in all positions except the EXT X and X-Y positions. In these two positions, X amplifier input operation is selected.

4-37. **Triggered Sweep Mode.** With the desired trigger source selected through TRIG SELECT switch S5, the level adjusted trigger output of the main trigger amplifier and switching is shaped by the Schmitt trigger. Provided a sweep retrace hold-off period is not in progress, the leading edge of the shaped trigger sets the timebase MV, enabling the bootstrap ramp generator to begin a single sweep ramp. The ramp output is applied through the RC sweep timing network which fixes the ramp speed. The ramp speed desired by the operator is chosen by positioning the TIME/CM switch to one of the 20 timebase positions (.5 uS to 1 SEC). The sweep speed is expressed as the period of time required to move the CRT beam 1 cm in the X direction on the CRT screen. When the sweep reaches its peak voltage, the turn-off bias is reached, causing a reset signal to turn off the timebase MV. This discontinues the enable signal to the bootstrap ramp generator, thus causing the retrace of the sweep ramp to begin. A hold-off time constant is generated during the retrace of the sweep ramp. This hold-off constant is tracked with the RC time constant of the linear sweep ramp to assure that the hold-off time is greater than the RC time constant for the sweep retrace. The hold-off voltage is applied as a trigger look-out bias of the input of the timebase MV to prevent retriggering of the timebase until the sweep has come fully to rest at its starting point. When the reset signal terminates, the timebase MV is once again released and can be turned on again by the next trigger to start the next sweep. The ramp output thus produced is amplified by the X output amplifier and applied to the horizontal deflection plates of the CRT.

4-38. The range between each pair of timebase positions is bridged by TIME/CM VARIABLE control R26. This control is continuously variable and provides a 3-to-1 range of decrease in the selected sweep range selected on the TIME/CM switch.

4-39. To ensure a bright trace when the trigger is lost or becomes unreliable during AUTO operation, the bright line auto sync circuit causes the timebase MV to free run by removing its bias. Free run operation can also be manually ordered by setting the TRIG SELECT switch to the FREE RUN position. The FREE RUN sweep can not be synchronized. This mode is provided primarily to maintain a free-running base line or display.

4-40. At the end of each sweep, the timebase MV sends out an end of sweep gate pulse. This pulse extends through the sweep retrace and hold-off period, during which time the timebase MV is in the reset state. During the alternate mode of channel selection, the leading edge of this end of sweep gate pulse is used to switch the channel selection by triggering the monostable chop MV, thus reversing the state of the channel switch MV. The end of sweep pulse also blanks out the CRT beam during the sweep retrace and while it is resting at the left edge of the CRT screen awaiting an initiating trigger.

4-41. Through the PULL X10 MAG switch (S9), the time/cm value associated with a given sweep speed can be increased to one-tenth the selected speed. This magnifies the display along the X axis and about the center of the graticule without altering the sweep period. The PULL X10 MAG switch achieves this effect by increasing the calibrated gain of the X output amplifier by a factor of 10. This X10 gain factor is also effective in magnifying the display during EXT X mode operation but is inoperative in the X-Y mode.

4-42. **X Amplifier Mode Operation.** In either the EXT X or X-Y positions the TIME/CM switch routes a -15V locking signal to the timebase MV, fixing it in its on state to intensify the CRT beam. At the same time, the R/C timing network is switched out of the circuit and replaced with the EXT X or CH1 input. These X input signals are applied to the bootstrap ramp amplifier. This converts the bootstrap ramp generator to a conventional linear amplifier and buffer for the X output amplifier. The X-Y display mode provides equal sensitivity (5 mV/cm) X-Y operation with full step and vernier attenuator capability. EXT X mode makes use of the X10 magnification gain control and permits the display of both channels against the EXT X input signal with all options. That is:

CH1 only
+CH2 or -CH2 only
CH1 and ±CH2 in dual trace (chopped or alternate channel switching)
CH1 ±CH2 (algebraically added or subtracted)
CH1 and CH2 cascaded

4-43. **ADDITIONAL CIRCUITS.** Not shown on the block diagram (figure 4-1) or on the functional diagrams (figures 4-2 and 4-3) are the circuits associated with the BEAM FINDER switch (S51), the CAL 1V output connector (J7), the NORMAL INTERNAL-EXT Z MOD switch (S11), and input connectors (J8 and J9). These are described in the paragraphs which follow. The related circuits may be found on the referenced schematics.

4-44. **BEAM FINDER Switch.** (See figures 6-4 and 6-5.) The BEAM FINDER switch reduces beam deflection to a small window on the CRT. This makes the beam visible regardless of other control settings. BEAM FINDER switch section S51A is shown on the timebase and X amplifier circuit (figure 6-4). In this circuit, depressing the switch acts to reduce the output current of the X amplifier. BEAM FINDER switch S51B is shown on the Z beam switching and Y output amplifier circuit (figure 6-5). In this circuit, the switch acts to reduce the output of the Y amplifier. Together, these two effects restrict the beam to the aforementioned window on the CRT. At the same time, BEAM FINDER switch section S51A supplies an output to the blanking amplifier in the power supplies and CRT circuit (figure 6-6) where it inhibits retrace blanking.

4-45. CAL 1V Output Connector. (See figure 6-6.) The CAL 1V output connector provides a calibrated 1 volt, 1 kHz, square wave output which can be used to adjust the oscilloscope for vertical sensitivity and probe compensation. This calibrated output is used only for basic checks in the absence of more elaborate test equipment and is calibrated into a 100-kilohm load. The source impedance of the internal calibrator is less than or equal to 1 kilohm.

4-46. NORMAL INTERNAL-EXT Z MOD switch. (See figure 6-6.) The NORMAL INTERNAL-EXT Z MOD switch permits the chop blanking of the CRT to be controlled either internally, from the chop MV, or externally from an outside source. In the EXT Z MOD position, the external source is supplied through input connectors J8 and J9 to, respectively, the high and reference sides of the input.

## 4-47. OPERATION INSTRUCTIONS.

4-48. CONTROLS, INDICATORS, AND CONNECTORS. All operating controls, indicators, and connectors on the front panel of the AN/USM-398 are described in table 4-1 and shown in figure 4-4. Controls and connectors on the rear panel are described in table 4-2 and shown in figure 4-5.

NOTE

The red-capped knobs on all concentric controls are to be read against the red panel marking information.

Channel 2 controls which are duplicates of channel 1 controls are not listed in table 4-1.

4-49. PREOPERATIONAL ADJUSTMENTS. To place the AN/USM-398 into operation, perform the procedures given in the following paragraphs.

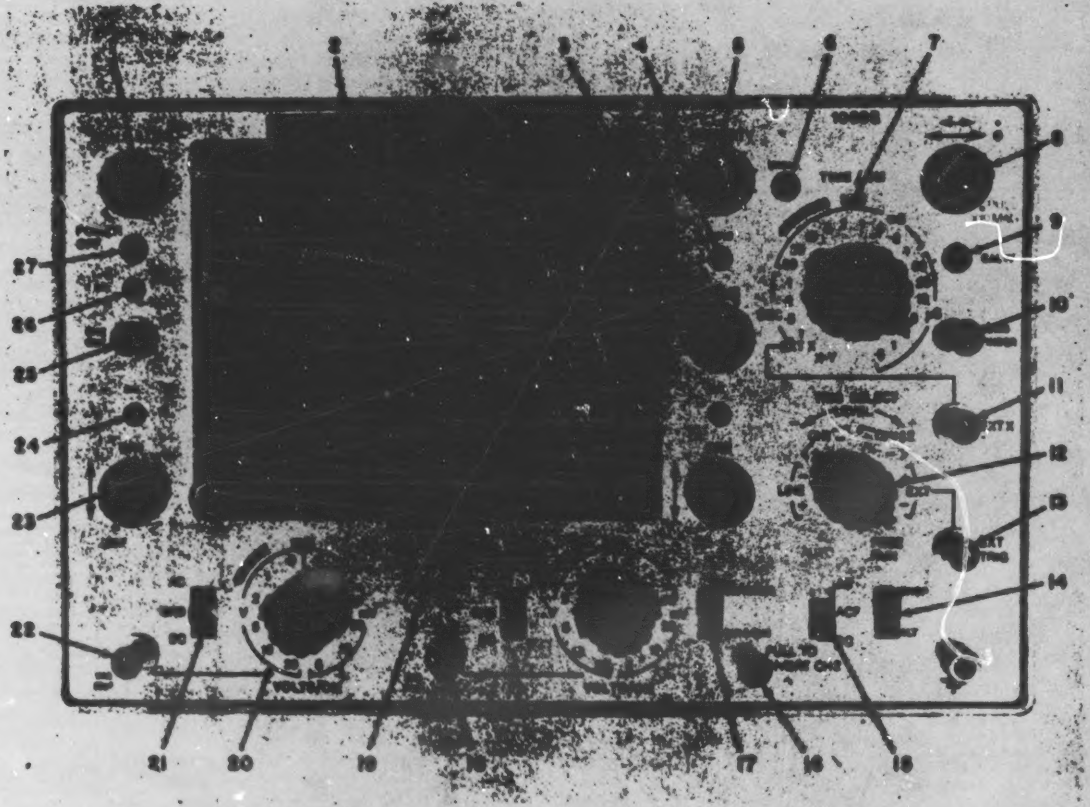

Figure 4-4. AN/USM-398 Front Panel Controls, Indicators, and Connectors

Table 4-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors

| FIG. 4-4 | CONTROL/INDICATOR/ CONNECTOR | SCHEMATIC DESIGNATION | FUNCTION |
|---|---|---|---|
| 1 | SCALE ILLUM | R37 | Adjusts brightness of CRT graticule background illumination. Turns power off in POWER OFF detent. |
| 2 | CATHODE RAY TUBE | V1 | Visually displays signals applied to vertical and horizontal amplifiers. |
| 3 | FOCUS | R39 | Adjusts sharpness of display. |
| 4 | ASTIG | R38 | Adjusts roundness of trace spot. |
| 5 | INTENSITY | R41 | Controls brightness of display. |
| 6 | UNCAL | DS100 | Lights when TIME/CM VARIABLE control (7) is not in CAL position. |
| 7 | TIME/CM (outer knob) | S8 | Selects horizontal sweep speed. Determines time required to sweep horizontal one graticule division. By pulling PULL X10 MAG knob (8), display can be expanded by 10, increasing fastest sweep to 50 ns/cm.<br>When set to EXT X selects horizontal control by external signal applied to EXT X BNC input jack (11).<br>When set to X-Y selects horizontal control by external signal applied to channel 1 BNC input jack (marked X) (22). |
| 7 | VARIABLE (inner knob) | R26 | Provides continuous and overlapping adjustment of sweep speed between calibrated positions of TIME/CM outer knob. Calibrated to TIME/CM position when set fully clockwise to CAL detent position. Turned counterclockwise, sweep speed decreases; however, TIME/CM readings are uncalibrated. |
| 8 | ←→ ○ (outer knob) | R27 | Provides coarse adjustment of horizontal position of display. |
| 8 | ←→ ● (inner knob) | R28 | Provides fine adjustment of horizontal position of display. |
| 8 | PULL X10 MAG (inner knob) | S9 | In pulled-out position, causes magnification of horizontal sweep or EXT X signal by factor of 10 |
| 9 | CAL 1V | J7 | Test point provides 1-kHz square wave at 1 volt p-p amplitude. May be used for vertical sensitivity calibration and divider probe compensation. |

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Table 4-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (Cont)

| FIG. 4-4 | CONTROL/INDICATOR/ CONNECTOR | SCHEMATIC DESIGNATION | FUNCTION |
|---|---|---|---|
| 10 | BEAM FINDER | S51 | Reduces gain of deflection amplifiers, thus limiting beam deflection to within the CRT graticule. Also operates on blanking amplifier to release sweep retrace blanking.<br>NOTE<br>Make sure INTENSITY control (5) is turned up high enough to make beam visible when using BEAM FINDER. |
| 11 | EXT X | J5 | Connector for an external horizontal input. |
| 12 | TRIG SELECT (outer knob) | S5 | Selects source of timebase trigger signal as follows:<br>LINE - Pickoff from ac line voltage, positive or negative slope.<br>CH1 - Pickoff from CH1 vertical amplifier signal, positive or negative slope.<br>CH1 & 2 - Pickoff from the displayed composite vertical deflection signal, positive or negative slope. (Not to be used in CHOP mode.) Use with ACF and DC trigger coupling.<br>EXT - Pickoff from external trigger applied to EXT TRIG jack (13), positive or negative slope.<br>FREE RUN - Sweep recurs at maximum repetition rate and with speed set by the TIME/CM switch. |
| 12 | LEVEL (inner knob) | R17, R6 | Selects point on amplitude of trigger signal that starts sweep. In AUTO position, sweep synchronizing triggers are produced automatically when signal exceeds 40-Hz repetition rate and exceeds minimum level. In absence of trigger signals, sweep runs free to produce bright line. |
| 13 | EXT TRIG | | Connector for external trigger signal. |
| 14 | CHOP-ALT switch | S96 | Selects display switching mode for dual trace vertical deflection.<br>ALT - CH1 and CH2 alternate with each sweep. Used for normal dual trace displays. |

Table 4-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (Cont)

| FIG. 4-4 | CONTROL/INDICATOR/ CONNECTOR | SCHEMATIC DESIGNATION | FUNCTION |
|---|---|---|---|
| 14(Cont) | | | CHOP - CH1 and CH2 alternate at 400 kHz. Used only when comparing signals on long time bases (slower than 1 ms/cm). Never used with CH1 & 2 trigger selection. Never used with timebase sweeps faster than 1 ms/cm. |
| 15 | AC-ACF-DC (Trigger Coupling) | S7 | Selects capacitive or direct coupling of trigger signal. Direct coupling (DC) is normally used for slow or erratic sync signals. Capacitive coupling (AC) blocks dc component but attenuates signals below 50 Hz. Fast capacitive coupling (ACF) attenuates signals below 50 kHz and is used to block unwanted low frequency components of the trigger signals. |
| 16 | PULL TO INVERT CH2 | S15 | Selects polarity for CH2 display. In pulled out position inverts CH2 polarity. |
| 17 | SEPARATE - CH1 & CH2 | S25 | Selects mode for display of vertical deflection channels, separate or added. |
| 18 | Y (CH2 input) | J2 | Connector for CH2 vertical input signal. |
| 19 | UNCAL | DS101 | Lights when either VOLTS/CM VARIABLE control (20) is not in CAL position. |
| 20 | CH1 VOLTS/CM (outer knob) | S2 (CH1)<br>S4 (CH2) | Selects channel 1 vertical deflection factor for calibrated measurements. |
| 20 | CH1 VARIABLE (inner knob) | S98 (CH1) R11<br>S97 (CH2) R12 | Provides continuous uncalibrated adjustments between calibrated positions of outer knob. Calibrated to VOLTS/CM positions when set fully clockwise to CAL detent position. |
| 21 | CH1 AC-GND-DC (Input Coupling) | S1 (CH1)<br>S3 (CH2) | Selects capacitive (AC) or direct (DC) coupling of input signal; or grounds (GND) the amplifier stages and disconnects the input to establish display reference of ground on the CRT graticule. |
| 22 | X (CH1 input) | J1 | Connector for CH1 vertical input signal and for horizontal input signal when TIME/CM switch (7) is set to X-Y position. |
| 23 | CH1 ↕ | S13, R13 (CH1)<br>S14, R14 (CH2) | Adjusts vertical position of CH1 display. Switches CH1 off when in OFF detent. |

Table 4-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (Cont)

| FIG. 4-4 | CONTROL/INDICATOR/ CONNECTOR | SCHEMATIC DESIGNATION | FUNCTION |
|---|---|---|---|
| 24 | BAL | R5, R10 | Adjusts to minimize vertical position change when rotating volts/cm switch. |
| 25 | CH2 OUT | J5 | Connector for output of CH2 vertical amplifier signal. |
| 26 | Y CAL | R470 | Provides adjustment of vertical sensitivity for both channels. |
| 27 | Power | DS1 | Lights when operating line power is applied. |
|  | Probe trimmer screw adjustment (not shown) | C32 | Adjusts frequency compensation of attenuator probe. |

Table 4-2. AN/USM-398 Rear Panel Controls and Connectors

| FIG. 4-5 | CONTROL/CONNECTOR | SCHEMATIC DESIGNATION | FUNCTION |
|---|---|---|---|
| 1 | 1A (fuse) | F1<br>XF1 | Protects oscilloscope power line from overload damage.<br>Holds fuse. |
| 2 | NORMAL INTERNAL - EXT Z MOD | S11 | Selects source of Z modulation signals for CRT. In NORMAL INTERNAL position, chop MV circuits of oscilloscope provide chop blanking pulses. In EXT Z MOD position, an external source provides brightness modulation pulses via EXT Z MOD connector (3). |
| 3 | EXT Z MOD | J8, J9 | Connectors for input of external blanking information to the CRT. Used when NORMAL INTERNAL - EXT Z MOD switch (2) is in EXT Z MOD position. |
| 4 | TRACE ROTATION | R633 | Permits angular adjustment of CRT trace with respect to the coordinate axes of the internal graticule. |
| 5 | 115V-230V | S12 | Matches power transformer primary of AN/USM-398 power supply to available line voltage. |

Figure 4-5. AN/USM-398 Rear Panel Controls and Connectors

**4-50. Power Connection.** The power requirement for the AN/USM-398 is 115/230 volts ac ±10%, 48 to 420 Hz, single phase. To connect power, proceed as follows:

**CAUTION**

The AN/USM-398 relies on convection cooling and must always be operated with reasonable air circulation.

1. Determine the line voltage and set the recessed 115V-230V slide switch on rear panel (using small screwdriver) as follows:

| Line Voltage | Switch |
|---|---|
| 104 to 126 volts ac | 115 |
| 208 to 252 volts ac | 230 |

**CAUTION**

Check to be certain that the 115/230 volt switch is set for the appropriate input voltage. Incorrect setting causes malfunction or damage to the instrument.

**NOTE**

Although the AN/USM-398 is normally wired with the primary of power transformer T1 set to receive a line voltage of 115/230 V, the wiring may be changed to permit the use of lower or higher line voltages (103/206 and 123/246 ±10 percent). This is accomplished as outlined in paragraph 5-122.

2. Turn the front panel SCALE ILLUM control counterclockwise to the POWER OFF detent position.

3. Connect power cable of AN/USM-398 to source of power.

4-51. Initial Settings. Before turning on power, perform the following procedure:

1. Set support/carrying handle to the required operating position. The handle is released by pulling both handle slides outward, and it can then be turned to lock in any one of five positions.

2. Set INTENSITY control fully counterclockwise.

3. Set CH1 vertical position control to mid-range and CH2 vertical position control to OFF detent.

4. Set CH1 and CH2 VOLTS/CM switches to 20mV with VARIABLE control at CAL detent.

5. Set CH1 and CH2 AC-GND-DC switches to GND.

6. Set SEPARATE - CH1 & CH2 switch to SEPARATE.

7. Set horizontal position control to mid-range.

8. Set TIME/CM switch to 1 mS.

9. Set TRIG SELECT switch to FREE RUN.

4-52. Turn-On Procedure. After performing initial settings, turn on power and obtain a trace as follows:

1. Turn the SCALE ILLUM control clockwise beyond the POWER OFF detent and observe that the associated power indicator lights.

2. Adjust INTENSITY control to obtain display of the required brightness.

NOTE

If visible display cannot be observed on the CRT, momentarily turn INTENSITY control fully clockwise and press BEAM FINDER pushbutton. This will produce a bright horizontal line near center of screen. Any offset of this line from center corresponds to an offset in the position control settings.

3. Center the display by adjusting CH1 and horizontal position controls.

4. Adjust FOCUS control to obtain most sharply defined trace after releasing BEAM FINDER and setting proper trace intensity.

4-53. OPERATING PROCEDURES. The following paragraphs describe the procedures to be followed in operating the AN/USM-398.

NOTE

Following initial receipt of the oscilloscope and before use each day (or at an interval determined by personnel in charge), perform the operator checkout described in paragraph 4-67.

4-54. Setting Up Vertical Channels. Set up the vertical channels of the AN/USM-398 as follows:

1. Connect signals to be displayed to one or both of the CH1 and CH2 BNC input connectors.

NOTE

When using unshielded signal leads, connect common ground lead to chassis of oscilloscope and equipment under test.

2. Depending on type of signal, set applicable AC-GND-DC switch to AC or DC position. Use the AC position to observe the ac component of signals with a dc component which is much larger than the ac component. Set switch for unused channel to GND. Also use GND position to locate baseline of vertical display.

3. Set applicable VOLTS/CM switch to desired sensitivity. Check that associated VARIABLE (inner) knob is at CAL detent unless vernier attenuation between fixed settings of VOLTS/CM switch is desired.

NOTE

The test probes supplied with oscilloscope introduce attenuation of 10X before signal appears at input to VOLTS/CM attenuators.

4. To obtain variation in sensitivity from the fixed settings of VOLTS/CM switch, turn VARIABLE counterclockwise out of CAL detent. UNCAL indicator goes on to indicate that AN/USM-398 is operating in an uncalibrated mode.

NOTE

The range of the VARIABLE control is approximately 3:1 so that its full adjustment overlaps the adjacent lower sensitivity range. Except at the CAL setting, the VARIABLE control is uncalibrated. At the CAL setting, the calibration corresponds to the setting of the VOLTS/CM switch. The UNCAL indicator illuminates when either the CH1 or CH2 VARIABLE control is out of the CAL position.

5. For vertical shift of the trace, adjust the vertical position controls (identified with vertical arrows).

6. When no input signal is applied and trace movement is detected when the setting of the VOLTS/CM

switch is altered, readjust the BAL screwdriver control for the respective input channel.

NOTE

> The BAL control will only need adjustment at infrequent intervals. Before adjusting the BAL control set the AC-GND-DC slide switch to GND and rotate the VARIABLE control on the VOLTS/CM switch to CAL. Always have the instrument fully warmed up and operating for a half hour before making BAL adjustments.

7. If CH2 is being used, check that PULL TO INVERT CH2 switch is pushed in, unless polarity inversion of CH2 display is desired.

**4-55. Use of Voltage Divider Probe at Vertical Channel Inputs.** An X10 voltage divider probe may be used to extend the voltage range and increase the input impedance of the vertical deflection input amplifiers. The input resistance of each vertical deflection channel is 1 MΩ shunted by approximately 28 pF. The effective capacity of the input lead must be added to this and the resultant impedance can often load the signal source. Therefore, it is advisable to use the voltage divider probe supplied with the AN/USM-396. The use of this 5 foot probe reduces the input capacity to approximately 15 pF and increases the input resistance to 10 MΩ, at the expense of the sensitivity. The probe contains a shunt RC network in series with the input and forms an attenuator with the input RC of the vertical channel. The trimmer capacitor (C32) in the probe termination is used to adjust probe frequency compensation by normalizing the probe to the scope. The internal 1-kHz calibration output, provided at the 1V CAL output jack, has a sufficiently fast rise time and is flat-topped enough to permit probe compensation without additional equipment. (See figure 4-6.)

**4-56. Single Channel Operation.** For single trace operation, turn the vertical position control for the desired channel clockwise out of the OFF position and turn the corresponding control for the other channel counterclockwise to the OFF position.

**4-57. Cascade Operation.** To obtain a high sensitivity (1 mV/cm) single trace condition with a bandwidth of dc to 5 MHz, operate CH1 and CH2 in series (cascade), using the output from the CH2 OUT connector. Proceed as follows:

1. Set both AC-GND-DC switches to DC.
2. Set both VOLTS/CM switches to 5 mV.

NOTE

> The output signal from the CH2 OUT connector is limited to 250 mV and has a gain of 5 with respect to the CH2 input. Consequently, the CH1 VOLTS/CM switch should always be set to 5 mV, 10 mV or 20 mV to avoid on-screen distortion during cascade operation.

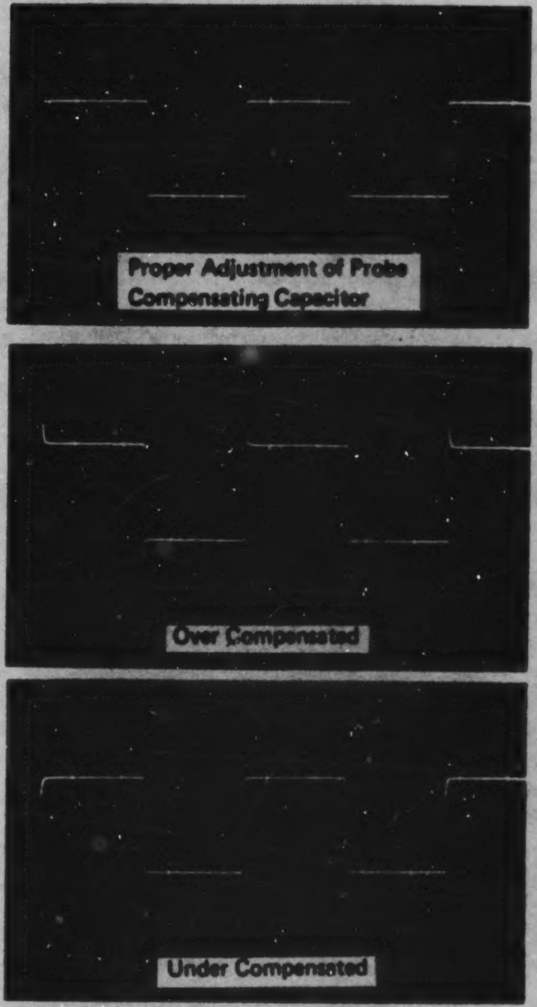

Figure 4-6. Probe Compensation Waveforms

3. Turn CH1 vertical position control clockwise out of OFF position.
4. Turn CH2 vertical position control counterclockwise to OFF detent.
5. Connect CH2 OUT connector J5 to CH1 input BNC J1 connector by means of a short BNC coaxial cable.
6. Connect signal to be displayed to CH2 input BNC connector J2.
7. Use CH1 vertical position control to adjust vertical position of trace.
8. If ac component of signal being displayed is small relative to dc component, set CH2 AC-GND-DC switch to AC.

6. The LEVEL control, concentric with the TRIG SELECT switch, allows selection of the triggering point on the trigger waveform and hence determination of the start of the horizontal trace. When the LEVEL control is set to AUTO, the trigger circuit automatically biases itself to the most sensitive trigger level condition, and AC couples the trigger signal. In the absence of a trigger signal (in auto mode) the timebase will free run and maintain a bright line sweep display at the selected sweep speed.

4-63. Horizontal Deflection, External Input. To obtain horizontal deflection under control of a signal applied to the EXT X input connector, set the TIME/CM switch to EXT X. The gain for this input is fixed at an uncalibrated value of approximately 0.8 V/cm and may be increased to 0.08 V/cm by using PULL X10 MAG switch.

4-64. X-Y Mode. The full range of sensitivity and attenuators for a single trace display of both vertical and horizontal deflection inputs may be utilized in the X-Y mode. Phase shift is nominally 3 degrees from dc to 500 kHz and the bandwidth is 1 MHz. To operate in the X-Y mode, proceed as follows:

1. Set TIME/CM switch to X-Y and both CH1 and CH2 position controls to mid-range.

2. Connect the signal which is to control horizontal deflection to X (CH1) input connector J1 and connect the signal which is to control vertical deflection to Y (CH2) input connector J2. Use procedures outlined in paragraph 4-54 to set coupling and attenuation.

NOTE

> In the X-Y mode (provided the SEPARATE - CH1 & CH2 switch is set to SEPARATE), the CH1 position control is inoperative and horizontal position is adjusted by the horizontal position controls (marked with horizontal arrows).

4-65. Z-Axis Input. If CRT intensity is to be modulated by an external signal, connect signal to EXT Z MOD connector on rear panel and switch the NORMAL INTERNAL - EXT Z MOD switch to the EXT Z MOD position. Typically, Z-axis modulation can provide reference marks by using a pulse input synchronous with the vertical display. Always return the NORMAL INTERNAL - EXT Z MOD switch to NORMAL INTERNAL when not using external Z modulation.

4-66. Turn-Off Procedure. To turn off the AN/USM-398, rotate SCALE ILLUM switch counterclockwise to POWER OFF detent.

4-67. OPERATOR CHECKOUT. Following initial receipt of the AN/USM-398, and prior to first usage of the instrument each day thereafter (or at an interval determined by personnel in charge), the operator should perform the following checkout procedure after a 20-minute warm-up period. The operator checkout establishes minimum performance standards for the AN/USM-398. All of the checks included in this procedure can be performed with the equipment covers in place. During this checkout, the oscilloscope should be operated in accordance with the preceding operating procedures, exercising the various control functions as required to obtain the indications in the following paragraphs.

4-68. Power-On Indications. Power indicator and CRT graticule background must light when power is turned on by rotating the SCALE ILLUM control clockwise from its POWER OFF detent position. The graticule must increase in brightness as rotation of the SCALE ILLUM control is continued.

4-69. Service Function Checks. With the oscilloscope operating in the sweep mode (TIME/CM to 1 mS, CH1 and CH2 VOLTS/CM to .5V, TRIG SELECT LEVEL to AUTO and AC-GND-DC to DC) and with the 1-volt, 1-kHz square wave calibrator output, supplied from the CAL 1V output connector on the front panel applied to both the CH1 and CH2 inputs, an independent representation of the 1-kHz square wave must appear for each channel when the associated CH1 or CH2 vertical position control is rotated clockwise from its OFF position. The trace for each channel must move up or down, independently of the trace for the other channel, as the corresponding CH1 or CH2 vertical position control is adjusted in its setting. The outer horizontal position control must be capable of adjusting the coarse positioning and the inner horizontal position control must be capable of adjusting the fine positioning of both traces along the X axis. Both traces must vary appropriately in brightness and resolution as the INTENSITY and FOCUS controls, respectively, are adjusted. With BEAM FINDER pushbutton pressed, display must be defocussed and reduced in deflection to a small rectangle at the center of the screen.

4-70. X-Y Mode. With the TIME/CM switch switched to the X-Y position, the display should be a single straight-line trace, aligned at a 45-degree angle with the horizontal graticule lines.

4-71. Trigger Control. With a common sine wave input (derived from the line power) applied to both CH1 and CH2 inputs, and with the TIME/CM switch set to 10 mS, the sweep must trigger on either the positive- or negative-going zero crossing of the displayed waveforms, depending on whether the TRIG SELECT switch is in the CH1+ or CH1- position. The trigger point of the sweep must be adjustable, varying according to the setting of the TRIG SELECT LEVEL control within its manual range. With the TRIG SELECT switch in the CH1+ position, the LEVEL control must be capable of placing the sweep trigger at any positive slope point between the negative and positive peaks of the displayed waveform. With the TRIG SELECT switch in the CH1- position, the LEVEL control must be capable of placing the sweep trigger at any negative slope point between the positive and negative peaks of the displayed waveform.

4-58. Dual Channel Operation. To obtain dual channel operation, connect inputs to both vertical deflection channels and turn both CH1 and CH2 vertical position controls clockwise out of the OFF position. Then select either the separate or added mode of displaying the two signals, as indicated in the following paragraphs.

4-59. To obtain two separate traces, set SEPARATE - CH1 & CH2 switch to SEPARATE. Select alternate or chopped mode using ALT - CHOP switch. During dual trace operation using the internal timebase, the operating guide lines listed below should be followed. (For complete details on use of the internal timebase, refer to paragraph 4-62.)

1. Try to use a trigger source selected by either the CH1, LINE or EXT position of the TRIG SELECT switch.

2. Avoid selecting the CH1 & 2 internal trigger source. However, if use of this position is unavoidable, set the AC-ACF-DC switch as follows:

   a. When both input signals have significant frequency components above 50 kHz, use ACF position of AC-ACF-DC switch.

   NOTE

   The ACF position of the AC-ACF-DC switch uses a high pass filter, which rejects and attenuates low frequencies.

   b. If the ACF position is not appropriate, use the DC position and carefully manipulate each vertical positioning control as well as the TIME/CM VARIABLE control until a stable display is achieved.

3. Never use chop mode when using the CH1 & 2 position of the TRIG SELECT switch. Use chop mode only:

   a. In the CH1, LINE and EXT positions of the TRIG SELECT switch.

   b. To avoid display blinking that would make measurements difficult on sweep speed ranges slower than 1 ms/cm.

   c. At sweep speeds slower than 1 ms/cm.

   d. With NORMAL INTERNAL - EXT Z MOD switch on rear panel set to NORMAL INTERNAL to blank switching transients in the CRT display.

4-60. To obtain a single trace representing the algebraic sum of the two inputs, set SEPARATE - CH1 & CH2 switch to CH1 & CH2 and position the added sum of the input signals on the CRT.

4-61. To obtain a single trace representing the algebraic differences of the two inputs, set SEPARATE - CH1 & CH2 switch to CH1 & CH2 and pull out PULL TO INVERT CH2. This function permits the comparison of two signals, by subtracting one from the other, and also permits common mode rejection between two related signals. Common mode rejection can be maximized by careful adjustment of either CH1 or CH2 VARIABLE control to exactly equalize channel sensitivities.

4-62. Horizontal Deflection, Internal Time Base Operation. To obtain horizontal deflection under control of the internally generated timebase, proceed as follows:

1. Set TIME/CM switch to any time scale position.

2. If a time scale between calibrated TIME/CM positions is desired, turn VARIABLE control counterclockwise out of CAL detent.

   NOTE

   The range of the VARIABLE control is approximately 3:1. Except at the CAL setting, the VARIABLE control is uncalibrated. At the CAL setting, the calibration corresponds to the setting of the TIME/CM switch. The UNCAL lamp illuminates to alert the operator when the VARIABLE control is not in CAL position.

3. If close examination of any portion of the trace is required, operate the PULL X10 MAG knob. The resulting expansion effectively increases the sweep length from 10 cm to 100 cm and increases the sweep speed by a factor of ten, while retaining the same sweep period.

4. For horizontal shift of the trace, adjust the horizontal position controls (identified by horizontal arrows). The outer knob provides coarse position control while the smaller, inner knob provides fine positioning. The fine control is especially useful in adjusting the display with the X10 magnification function active. Pulling the small knob (PULL X10 MAG) activates the X10 magnification function.

5. The timebase may be operated either in a free run condition or may be triggered from the positive or negative slope of a signal as determined by the setting of the TRIG SELECT switch. The triggering sources selected by the TRIG SELECT switch in its various positions are as follows:

   a. LINE - the line input frequency derived from the transformer in the power supply section.

   b. CH1 - the CH1 trigger amplifier.

   c. CH1 & CH2 - the buffer amplifier (irrespective of which beam is displayed).

   d. EXT - an external triggering source, connected to the EXT TRIG BNC connector.

   e. FREE RUN - no trigger used.

4-72. Timebase Calibration. As an approximate check of the timebase calibration, count the number of cycles of line power voltage displayed on the CRT. Five cycles of a 50-Hz line power input or six cycles of a 60-Hz line power input should be displayed across the 10 cm of graticule width for both CH1 and CH2. The number of cycles must vary in accordance with the setting of the TIME/CM switch as the TIME/CM switch is adjusted. Pulling out the inner knob (PULL X10 MAG) must expand both traces along the X axis by a factor of 10.

4-73. Vertical Calibration. With both the CH1 and CH2 VOLTS/CM switches set to .5 V, apply a 1-volt square wave from the internal calibrator to CH1 and CH2 inputs. Each of the two displayed waveforms must have a 2-cm vertical amplitude. With each waveform in succession centered vertically on the graticule, the amplitude must vary in accordance with the setting of the associated VOLTS/CM switch as the switch is varied. During these adjustments, there should be no appreciable vertical depositioning of the waveform as the VOLTS/CM switches vary the attenuation. If traces shift appreciably, check BAL adjustment for the respective channel after 30-minute warmup.

4-74. Channel Switching Modes. With both channels active, check that channel switching takes place reliably with NORMAL INTERNAL - EXT Z MOD switch in the NORMAL INTERNAL position and with CHOP-ALT switch set in succession to both the CHOP and ALT positions. Vary setting of the TIME/CM switch as required to make each type of channel switching clearly visible. While checking the chop mode, note whether chop transients in the display are blanked.

**NOTE**

Do not attempt to use chop mode operation with CH1 & 2 trigger.

4-75. Inverting and Channel Summing Modes. When the PULL TO INVERT CH2 control is pulled out, the CH2 trace must invert. When the SEPARATE - CH1 & CH2 switch is set to CH1 & CH2, and with both VOLTS/CM switches at a common setting, the CH1 and CH2 traces must add, producing a single trace of double amplitude, or subtract, producing a single straight-line trace, depending on the setting of the PULL TO INVERT CH2 switch.

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KEP-HO-110

Electronic Principles Department

# ELECTRONICS HANDBOOK

15 April 1975

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Keesler Technical Training Center
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Supersedes Student Handout KEP 110, 1 July 1974, which may be used until supply is exhausted.

## ABBREVIATIONS OF FREQUENTLY USED TERMS

| | |
|---|---|
| AC | alternating current |
| A | ampere |
| amp | amplifier - ampere |
| AM | amplitude modulation |
| ant | antenna |
| AF | audio frequency |
| AFC | automatic frequency control |
| ANL | automatic noise limiter |
| calbr | calibration |
| C | capacitance - coulomb |
| CRT | cathode-ray tube |
| c | centi |
| chrg | charge |
| cir | circuit |
| coax | coaxial |
| comm | communications |
| CW | continuous wave |
| xtal | crystal |
| d | deci |
| dB | decibel |
| dBm | decibel with 1 milliwatt reference |
| diam | diameter |
| DC | direct current |
| DSB | double-sideband |
| elec | electrical |
| EMF | electromotive force |
| elct | electronics |
| elem | element |
| E | energy - voltage |
| F | farad |
| F/F | flip-flop |
| f | frequency |
| FM | frequency modulation |
| G | giga |
| h | hecto |
| H | henry |
| Hz | hertz |
| Z | impedance |
| incr | increment |
| $X_L$ | inductive reactance |
| $f_{if}$ | intermediate frequency (IF) |
| ICW | interrupted continuous wave |
| k | kilo |
| kHz | kilohertz |
| kΩ | kilohm |
| kV | kilovolt |
| kW | kilowatt |
| L | inductance (self) |
| LO | local oscillator |
| LF | low frequency |
| H | magnetic field strength |
| mo | master oscillator |
| MOPA | master-oscillator power amplifier |
| M | mega |
| MHz | megahertz |
| MW | megawatts |
| m | meter |
| μ | micro |
| μA | microampere |
| μF | microfarad |
| μH | microhenry |
| mic | microphone |
| μs | microsecond |
| μV | microvolt |
| m | milli |
| mA | milliampere |
| mH | millihenry |
| mV | millivolt |

| | |
|---|---|
| mW | milliwatt |
| MCW | modulated continuous wave |
| MTI | moving target indicator |
| n | nano |
| neg | negative |
| NPN | negative-positive-negative |
| $\Omega$ | ohm |
| osc | oscilator |
| PIV | peak inverse voltage |
| PP | peak to peak |
| pent | pentode |
| pm | permanent magnet |
| PM | phase modulation |
| p | pico |
| PNP | positive-negative-positive |
| pot | potentiometer |
| P | power |
| $F_R$ | power factor (PF) |
| prim | primary |
| pc | pulsating current |
| PAM | pulse amplitude modulation |
| PCM | pulse code modulation |
| $t_p$ | pulse duration (PD) |
| PDM | pulse duration modulation |
| PFM | pulse frequency modulation |
| P-M | pulse modulation |
| $f_p$ | pulse repetition frequency (PRF) |
| PRT | pulse recurrence time |
| PW | pulse width |
| radar | radio detection and ranging |
| RF | radio frequency |
| X | reactance |
| R | resistance |
| RMS | root mean square |
| s | second |
| sig | signal |
| SNR | signal-to-noise ratio |
| SSB | single-sideband |
| std | standard |
| swr | standing-wave ratio |
| T | tera |
| t | time |
| T | time constant (TC) |
| trans | transformer |
| TWT | traveling-wave tube |
| VTVM | vacuum-tube voltmeter |
| V | volt |
| VOM | volt-ohm-milliammeter |
| W | watt |
| Wh | watthour |
| $\lambda$ | wavelength |
| WW | wire wound |

## DEFINITIONS

**ABSOLUTE SYSTEM** - System of units in which numbers of units are chosen as fundamental and all other units are derived from them.

**ABSORPTION** - Loss of energy, due to conversion into heat or other forms, in the transmission of waves over radio or wire paths.

**ABSORPTION WAVEMETER** - Instrument used for measuring the wavelength and/or frequency of a given source by means of a calibrated resonant circuit, loosely coupled to the source, indicating resonant as maximum current in the calibrated circuit.

**ACCELERATING ANODE OR ELECTRODE** - (1) Used in cathode-ray and other electron tubes to increase the velocity of the electrons in a beam. It is operated at a high positive potential with respect to the cathode. (2) Used for drawing electrons away from a light-sensitive cathode of a Farnsworth image dissector tube for a television camera.

**ACCEPTOR** - An impurity added to a crystal during manufacture to create a semiconductor. An impurity acceptor creates a hole in the valence band.

**ACCESS TIME** - Time interval which is characteristic of a storage unit in an electronic computer and is essentially a measure of the time required to communicate with that unit.

**ACCUMULATOR** - Device in an electronic computer which stores a number and which, on receipt of another number, adds it to the number already stored, and stores the sum.

**AC GENERATOR** - (1) Rotating electrical machine, generally known as an alternator, that converts mechanical power into alternating current. (2) Oscillator, or any other device, designed for the purpose of producing alternating current.

**ACORN TUBE** - Button or acorn-shaped vacuum tube, with no base, for UHF applications.

**ACTIVE DEVICE** - One through which large amounts of power can be controlled with smaller amounts of power; e.g., transistor, vacuum tube, or relay.

**ACTIVE OR ACTUAL POWER** - Average of values of instantaneous power taken over 1 cycle.

**ACTUATING DEVICE** - Manually- or automatically-operated mechanical or electrical device which operates electrical contacts to effect signal transmission.

**ADAPTER** - Fitting which is designed to adapt a jack, plug, or receptacle so as to make possible electrical connection by means other than those originally intended.

**ADDER** - Device in an electronic computer which can form the sum of two or more numbers of quantities impressed upon it.

**ADJUSTABLE VOLTAGE DIVIDER** - Wire-wound resistor having one or more movable terminals. Terminals can be moved along the length of the exposed resistance wire until the desired voltage values are obtained.

**ADMITTANCE** - Lack of opposition to the flow of alternating current in a circuit (the reciprocal of impedance), usually expressed in mhos.

**AIR CAPACITOR** - Capacitor using air as the dielectric material between its plates.

**AIR-CORE COIL** - Coil without metal in its magnetic circuit.

**AIR-CORE TRANSFORMER** - Transformer (usually RF) having a nonmetallic core. Transformers wound on a solid insulating substance, such as isolantite, are assumed to have an air core.

**ALLOY** - Mixture or combination of two or more metals.

**ALNICO** - Alloy consisting chiefly of aluminum, nickel, and cobalt, with high magnetic retentivity; it is used to make small, powerful permanent magnets.

**ALPHA** - Forward current transfer ratio for a common-base configuration.

**ALTERNATING CURRENT (AC)** - Current that is reversing in polarity.

**ALTERNATING-CURRENT PULSE** - Alternating-current wave of brief duration.

**ALTERNATING-CURRENT RESISTANCE** - Total resistance offered by a device in an AC circuit.

**ALTERNATING GRID VOLTAGE** - The AC component of grid voltage.

**ALTERNATING-CURRENT COMPONENT OF CURRENT** - That portion of a pulsating current represented by the changing rate and/or direction of electron flow; that is, in the absence of the DC component, the average electron displacement is zero.

**ALTERNATING-CURRENT COMPONENT OF VOLTAGE** - That portion of a pulsating voltage which is responsible for the nonuniform electron flow in a conductor to which the pulsation voltage is applied; if the pulsating voltage reverses its polarity, the AC component is responsible for the reversals of the direction of electron flow as well as for the change in the rate of flow.

**ALTERNATION** - Variation, either positive or negative, of a waveform from zero to maximum and back to zero (equals one-half of a cycle).

**ALTERNATOR** - Rotating machine which generates alternating current.

**AMMETER** - Instrument used for measuring the amount of current in amperes.

**AMORPHOUS** - Devoid of regular structure, especially of crystaline structure.

**AMPERE** - Practical unit of current. One ampere will flow through a resistance of 1 ohm when a difference of potential of 1 volt is applied across terminals.

**AMPERE-HOUR** - Quantity of electricity that passes through a circuit in 1 hour when the rate of flow is 1 ampere.

**AMPERE-TURNS** - Product obtained by multiplying the number of turns in a coil by the current in amperes flowing through the coil.

**AMPLIFICATION** - Increase in magnitude in transmission from one point to another, or the process causing this increase. It may be expressed as a ratio, or by extension of the term, in decibels.

**AMPLIFIER** - Device for increasing the power associated with a phenomenon without appreciably altering its quality, through control by the amplifier input of a larger amount of power supplied by a local source to the amplifier output.

**AMPLITUDE** - (1) Maximum displacement from the zero position of an alternating current or any other periodic phenomenon. (2) Amplitude is commonly used, in a general sense, to indicate the size or magnitude of a wave or current.

**AMPLITUDE DISTORTION** - Changing of a wave shape in amplitude so that it is no longer proportional to its original amplitude. This occurs in an amplifier or other device when the amplitude of the output is not exactly a linear function of the input amplitude.

**AMPLITUDE MODULATION** - Modulation in which the amplitude of a carrier is the characteristic varied.

**ANALOG COMPUTER** - (1) A computing machine that works on the principle of measuring, as distinguished from counting, in which the measurement obtained, as voltages, resistance, etc., are translated into desired data.

**AND-GATE** - Gate whose output is energized when and only when every input is in its prescribed state. An AND-gate performs the function of the logical "AND." Also called AND-circuit.

**ANGLE MODULATION** - Modulation in which the angle of a sinewave is varied.
NOTE: Phase and FM are forms of angle modulation.

**ANGLE OF INCIDENCE** - Angle between the perpendicular to a reflecting surface at the point at which an electromagnetic wave strikes a surface and the direction from which the wave approaches the surface. A wave perpendicular to the surface has a zero angle of incidence.

**ANGLE OF LAG** - Angle by which one alternating electrical quantity lags another of the same cyclic period.

**ANGLE OF LEAD** - The time or angle by which one alternating electrical quantity leads another of the same cyclic period.

**ANGLE OF RADIATION** - Angle between the surface of the earth and the center of the beam of energy radiated upward into the sky from a transmitting antenna.

**ANODE** - (1) Positive electrode; the collector of a solid-state diode; the plate of a vacuum tube; the positive pole of a tube toward which the electrons move. (2) Positive electrode of an electrochemical device (such as a primary or secondary electric cell) toward which the negative ions are drawn.

**ANODE VOLTAGE** - Voltage between the anode and cathode.

**ANTENNA** - Any structure or device used to detect or radiate electromagnetic waves; specifically that part of a radar or of a radio-sending or radio-receiving set that contains, or itself consists of, that apparatus that radiates waves or receives them.

**ANTENNA ARRAY** - Arrangement of antenna elements, usually dipoles, which results in desirable directional characteristics.

**ANTENNA CURRENT** - An RF current that flows in an antenna.

**ANTENNA MATCHING** - Process of adjusting impedances so that the impedance of an antenna equals the characteristic impedance of its transmission line.

**ANTIRESONANT FREQUENCY** - Frequency of a crystal unit for a particular mode of vibration at which neglecting dissipation, the effective impedance of the crystal unit is infinite.

**APPARENT POWER** - The power value obtained in an AC Circuit by multiplying the effective values of voltage and current - the result is expressed in volt-amperes.

**AQUADAG** - Colloidal suspension of graphite deposited on the inner side walls of cathode-ray tubes to serve as an electrostatic shield or an accelerating anode.

**ARC** - A discharge of electricity through a gas, normally characterized by a voltage drop approximately equal to the ionization potential of the gas.

**ARMATURE** - The revolting part of a generator, motor, or other electromagnetic device which has current induced in it by motion. (The motion may be relative only; i.e., the armature itself may be stationary, and the field rotate around it.)

**ARMATURE CORE** - Assembly of laminations forming the magnetic circuit of the armature.

**ARMSTRONG OSCILLATOR** - Inductive feedback oscillator, that consists of a tuned-base (grid) circuit and untuned-tickler coil in the collector (plate) circuit. Control of feedback is accomplished by varying the coupling between the tickler and the base (grid) circuit.

**ARTIFICIAL LINE** - Circuit made up of lumped constants, which is used to simulate various characteristics of a transmission line.

ASTIGMATISM - In an electron-beam tube, a focus defect in which electrons in different axial planes come to focus at different points.

ATOM - Smallest particle into which matter can be divided.

ATOMIC NUMBER - In chemistry, a number representing the relative position of an element in the periodic table in which the elements are arranged in the order of either their atomic weights or their nuclear charges; number representing the positive charge or number of protons in the nucleus of the atom of an element.

ATTENUATOR - Device for reducing the amplitude of a current. Attenuators are most commonly combinations or networks of resistance, either fixed or adjustable. In its many different forms and applications, the attenuator becomes known variously as pad, gain control, level adjustor, volume control, etc.

ATTRACTION - Force that tends to make two objects approach each other. Attraction exists between two unlike magnetic poles (North and South) or between two unlike static charges (plus and minus).

AUDIO FREQUENCY - Frequency which can be detected as a sound by the human ear. The range of audio frequencies extends approximately from 15 to 20,000 hertz.

AUDIO-FREQUENCY CHOKE - Choke used to impede the flow of audio-frequency currents; generally a coil wound on an iron core.

AUDIO-FREQUENCY OSCILLATOR - Oscillator unit or circuit producing oscillations at audio frequencies; such as an oscillator used with headphones and a telegraph key for code practice.

AUDIO-FREQUENCY TRANSFORMER - Transformer designed to transfer audio-frequency signals from one circuit to another. Commonly used to match two different circuit impedances and permit maximum power transfer.

AUTOMATIC CIRCUIT BREAKER - Device that automatically opens a circuit, usually by electromagnetic means, when the current exceeds a safe value.

AUTOMATIC FREQUENCY CONTROL - An arrangement whereby the frequency of an oscillator is automatically maintained within specified limits.

AUTOMATIC GAIN CONTROL - Type of circuit used to maintain the output volume of a receiver constant, regardless of variations in the signal strength applied to the receiver.

AUTOMATIC NOISE LIMITER - A circuit that automatically cuts off all noise peaks that are stronger than the highest peak in the desired signal being received, thereby preventing loud crashing noises due to strong atmospheric or manmade interference.

AUTOTRANSFORMER - Transformer with a single winding (electrically) in which the whole winding acts as the primary winding, and only part of the winding acts as the secondary (stepdown); or part of the winding acts as the primary and the whole winding acts as the secondary (stepup).

AVALANCHE BREAKDOWN - A breakdown that is caused by the cumulative multiplication of charge carriers through field-induced impact ionization.

AVERAGE VALUE - Average of many instantaneous amplitude values taken at equal intervals of time during an alternation (half-cycle) of alternating current. The average value of one alternation of a pure sine wave is 0.637 times its maximum or peak amplitude value.

AXIS - Straight line, real or imaginary, that passes through a body and about which the body may, or actually does, revolve.

BACK BIAS - Degenerative or regenerative voltage which is fed back to circuits before its originating point. It is usually applied to a control anode of a tube.

BACK ELECTROMOTIVE FORCE - The counter EMF of any system is the effective EMF within the system which opposes the passage of current in a specified direction.

BACK-TO-FRONT RATIO - Ratio used in connection with antennas, metal rectifiers, or any device in which signal strength or resistance in one direction is compared to that in the opposite direction.

BALANCED CIRCUIT - A circuit, the two sides of which are electrically alike and symmetrical with respect to a common reference point, usually ground.

BALANCED TRANSMISSION LINE - Transmission line having equal conductor resistances per unit length and equal impedance from each conductor to earth and to other electrical circuits.

BALLAST RESISTOR - Special type of resistor to compensate for fluctuations in AC power line voltage. It is usually connected in series with the power supply to a receiver or amplifier. The resistance of a ballast resistor increases rapidly with increases in current through it, thereby tending to maintain essentially constant current despite variations in line voltage.

BAND - Range of frequency spectrum between two defined limits.

BANDPASS - Expresses the frequencies which will pass between the limits of a band at the desired fraction (usually halfpower) of the maximum output.

BANDWIDTH - Range within the limits of a band. The width of a bandpass filter is generally taken as the limits between which its attenuation is not more than 3.0 decibels from the average attenuation throughout its bandpass. Also used in connection with receive selectivity, transmitted frequency spectrum occupancy, etc.

BARRIER LAYER - Surface of contact between a metal and semiconductor. It acts as a rectifier of alternating currents. Some barrier layers when illuminated, generate a voltage through photovoltaic action. The junction between copper and curous oxide in the photoelectric cell is a barrier layer.

BASE - See TRANSISTOR BASE.

BATTERY - Device for converting chemical energy into electrical energy.

BEAM FORMING PLATES - Electron beam focusing elements in power tetrodes and in cathode-ray tubes.

BEAM POWER TUBE - An electron-beam tube in which directed electron beams contribute substantially to its power-handling capability, and in which the control grid and the screen grid are essentially aligned.

BEAT FREQUENCY - One of the two additional frequencies generated when signals of two different frequencies are combined. The beat frequencies are equal to the sum and the difference of the two original frequencies.

BETA - Forward current transfer ratio of a common-emitter configuration.

B-H CURVE - Curve plotted to show successive states during magnetization of a ferromagnetic material. A normal magnetization curve is a portion of a symmetrical hysteresis loop, while a virgin magnetization curve shows what happens the first time the material is magnetized.

BIAS - Average DC voltage or current used to establish an operating point.

BIFILAR - Transformers, inductors, etc., are said to be bifilar wound, when, to achieve a desired balance (similarity between winding), two conductors are wound simultaneously side-by-side.

BIMETALLIC STRIP - Strip formed of two dissimilar metals welded together. The metals have different temperaure coefficients of expansion, causing the strip to bend or curl when the temperature changes.

BINARY - (1) Characteristic or property involving a choice or selection, using only two symbols: such as 0 and 1, on or off, go or stop. (2) A number system whose successive digits are interpreted as coefficients of the successive powers of the base two.

**BLEEDER RESISTOR** - Resistor which is used to draw a fixed current. Also used, as a safety measure, to discharge filter capacitors after the circuit is deenergized.

**BLOCK DIAGRAM** - Diagram in which the essential units of any system are drawn in the form of blocks, and their relation to each other indicated by appropriate connecting lines.

**BLOCKING OSCILLATOR** - An oscillator operating intermittently with bias increasing during oscillation to a point where oscillations stop, then decreasing until oscillation is resumed.

**BREADBOARD** - In electronics or servo work, an arrangement in which components are fastened temporarily to a board or chassis for experimental purposes.

**BREAKDOWN OF A SEMICONDUCTOR DIODE** - A change which takes place as reverse bias is increased from a region of high-dynamic resistance to a region of substantially lower dynamic resistance; a sharp increase in reverse current for increasing magnitude of bias.

**BREAKDOWN VOLTAGE** - (1) Voltage at which an insulator or dielectric ruptures, or at which ionization and conduction take place in a gas or vapor. (2) Of a semiconductor diode, the voltage measured at a specified current in the breakdown region.

**BRIDGE CIRCUIT** - Network which is so arranged that when an electromotive force is present in one branch, the response of a suitable detecting device in another branch may be made zero by a suitable adjustment of the electrical constants of still other branches.

**BRIDGED T-NETWORK** - Network with the two series impedances of the T bridged by a fourth impedance.

**BRIDGE RECTIFIER** - Full-wave rectifier with four elements connected in a bridge circuit so that direct voltage is obtained from one pair of opposite junctions when alternating voltage is applied to the other pair.

**BUFFER** - Circuit or component which isolates one electrical circuit from another. Usually refers to amplifiers used for this purpose.

**BUFFER DRUM** - In a computer, a magnetic drum designed to accept information from input or output circuits and retain it until used.

**BYPASS CAPACITOR** - A capacitor for providing an AC path of comparatively low impedance around some circuit or element.

**CALIBRATION** - Process of comparing an instrument or device with a standard to determine its accuracy or to devise a corrected scale.

**CAPACITANCE** - (1) Ability to store electrical energy, measured in farads, microfarads, or picofarads. (2) Property of a capacitor which determines the amount of electrical energy which can be stored in it by applying a given voltage. (3) Property of two or more bodies which enables them to store electrical energy in an electrostatic field between them. (4) Ratio of the electric charge transferred from one conductor to another, the difference of potential between the conductors. (5) Of a semiconductor diode, the small-signal capacitance measured between the terminals of the diode under specified conditions of bias and frequency.

**CAPACITIVE REACTANCE** - The opposition of a capacitor to a change in an applied voltage, and dissipates no power, to alternating current or pulsating direct current. Measured in ohms, it is calculated as: $X_C = 1/2\pi fC$.

**CAPACITOR** - Device consisting essentially of two conducting surfaces separated by an insulating material or dielectric such as air, paper, mica, glass, or oil. A capacitor stores electrical energy, blocks the flow of direct current, and reacts when applied voltage decreases to permit the flow of alternating current, to a degree dependent on the capacitance and the frequency.

**CAPACITOR-INPUT FILTER** - Filter which has a capacitor connected directly across (in parallel with) its input.

**CARRIER FREQUENCY** - The frequency of the unmodulated fundamental output of a radio transmitter, normally measured in herts.

**CATHODE** - An electrode through which a primary stream of electrons enters the interelectrode space.

**CATHODE BIAS** - Method of biasing a vacuum tube by placing the biasing resistor in the common cathode-return circuit.

**CATHODE CURRENT** - The net current from an electrode into the interelectrode space.

**CATHODE-RAY TUBE** - Vacuum tube in which the instantaneous position of a sharply focused electron beam, deflected by means of electrostatic and/or electromagnetic fields, is indicated by a spot of light produced by the impact of the electrons in a flourescent screen at one end of the tube.

**CAT WHISKER** - Small, sharp-pointed wire used to make contact with a sensitive point of the surface of a semiconductor.

**CAVITY RESONATOR** - (1) Hollow metallic cavity in which electromagnetic oscillations can exist when the cavity is properly excited. (2) Space normally bounded by an electrically conducting surface in which oscillating electromagnetic energy is stored, and whose resonant frequency is determined by the geometry of the enclosure.

**CHARACTERISTIC CURVE** - Graph plotted to show the relation of voltage and current values. An example is a curve to show how the plate current changes with variations in the plate voltage, holding the grid voltage constant.

**CHARACTERISTIC IMPEDANCE** - Impedance of a transmission line which would be measured if that line were uniform in all respects throughout its length and of infinite length. A line will appear to be infinitely long if terminated in a load equal to its characteristic impedance.

**CHARGE** - (1) Electrical energy stored in a capacitor or battery or held on an insulated object. (2) Quantity of electrical energy held on an insulated object or in a capacitor under static conditions.

**CHARGED BODIES** - Bodies with an excess or deficiency of electrons.

**CHARGE DENSITY** - Charge per unit area on a surface or charge per unit volume in space.

**CHARGING CURRENT** - (1) Current that charges an electrical storage unit. (2) Current that restores energy to a storage battery.

**CHOKE** - An inductor used to smooth the flow of pulsating direct current or alternating current by means of its self-inductance without appreciable effect on the flow of DC.

**CIRCUIT** - Electronic path between two or more points.

**CIRCUIT DIAGRAM** - Schematic drawing of the electrical connections of an electronic device or equipment.

**CLASS A AMPLIFIER** - Amplifier in which the input bias and alternating input amplitudes are such that output current flows at all times. Operation in the linear portion of its characteristic curve gives an output amplified facsimile of the input.

**CLASS AB AMPLIFIER** - Amplifier in which the input bias and alternating input amplitudes are such that output current flows for appreciably more than half but less than the entire input signal cycle (between class A and class B operation).

**CLASS B AMPLIFIER** - Amplifier in which the input bias is approximately equal to the cutoff value, so that the output current is approximately zero when no input signal is applied and flows for approximately one-half of each cycle when an alternating input signal is applied.

**CLASS C AMPLIFIER** - Amplifier in which the input bias is appreciably greater than the cutoff value, so that the output current is zero when no alternating input signal is applied and flows for appreciably less than one-half of each cycle when an alternating input signal is applied.

**CLOCK** - Primary source of electronic computer synchronizing signals.

**CLOCK FREQUENCY** - In SAGE, the master frequency of periodic pulses scheduling the operation of the computer.

**CLOSE COUPLING** - Degree of coupling greater than the critical coupling.

**COAXIAL** - Having one axis within another, as a coaxial cable, with a single cylindrical conductor suspended in the center of another conductor.

**COAXIAL CABLE** - Cable, used as a transmission line, consisting of one conductor, usually a small copper tube or wire, within and insulated from another conductor or larger diameter, usually copper tubing or copper braid. The outer conductor may or may not be grounded. Radiation from this type of line is practically zero.

**COEFFICIENT OF COUPLING** - Numerical indicator of the degree of coupling existing between two circuits.

**COIL** - Turns of wire wound on an iron core or on a coil form made of insulating material so as to be self-supporting. A coil offers considerable opposition to the passage of alternating current but very little opposition to direct current.

**COLD CATHODE** - A cathode whose operation does not depend on its temperature being above the ambient temperature.

**COLLECTOR** - In a transistor, an electrode through which a primary flow of carriers leaves the interelectrode region.

**COLLECTOR JUNCTION** - Of a transistor, a junction normally biased in the high resistance direction, through which the current can be controlled by the introduction of minority carriers.

**COLPITTS OSCILLATOR** - An LC oscillator in which a parallel-tuned tank circuit is connected between base and collector or grid and plate, with the tank capacitance containing two voltage-dividing capacitors in series and with their common connection at emitter or cathode potential.

**COMMUTATION** - Mechanical process of converting the alternating current which flows in the armature of DC generators into the DC generator output.

**COMMUTATOR** - Device used on electric motors or generators to maintain an unidirectional current.

**COMPENSATED SEMICONDUCTOR** - A semiconductor in which one type of impurity or imperfection (e.g., donor) partially cancels the electrical effects of another type of impurity or imperfection (e.g., acceptor).

**COMPENSATED VOLUME CONTROL** - Device in a radio receiver that changes the tonal balance of the loudspeaker output for different output levels to compensate for corresponding variations in the response characteristics of the human ear.

**COMPONENT** - A functional part of a subsystem or equipment which is essential to operational completeness of the subsystem or equipment, and which may consist of a combination of parts, assemblies, accessories, and attachments. Examples are radio transmitter unit, radio receiver unit, amplifier unit, analyzer unit, computer unit, and control box.

**CONDUCTANCE** - Ability of a material to conduct or carry an electric current. It is the reciprocal of the resistance and is expressed in mhos.

**CONDUCTION BAND** - A range of states in the energy spectrum of a solid in which electrons can move freely.

**CONDUCTION CURRENT** - Movement of free charges composing an electric current.

**CONDUCTION ELECTRONS** - The electrons in the conduction band of a solid, which are free to move under the influence of an electric field.

**CONDUCTION FIELD** - The energy surrounding a conductor when an electric current is passed through the conductor, which, because of the difference in phase between the electrical field and magnetic field set up in the conductor, cannot be detached from the conductor.

**CONDUCTOR** - Material which permits the passage of an electric current.

**CONDUIT** - Tube of steel, tile, wood, or other material through which cables or wires can be passed.

**CONE** - Cone-shaped part of a loudspeaker that actually moves the air.

**CONSTANT** - Anything invariable or not subject to change.

**CONTACT** - Part of an equipment designed to touch a similar contact to permit current to flow, or designed to break this union to cause current to cease.

**CONTINUITY** - The presence of a complete path through which current can flow.

**CONTINUOUS WAVES** - Successive oscillations of waves, identical under steady-state conditions. Generally, radio waves are of a constant amplitude and constant frequency.

**CONTROL ELECTRODE** - An electrode used to initiate or vary the current between two or more electrodes.

**CONTROL GRID** - Grid electrode, originally placed between the cathode and anode of an electron tube, for use as a control electrode.

**CONTROL GRID BIAS** - Average DC voltage between the control grid and cathode of a vacuum tube.

**CONTROL TRANSFORMER** - Synchro in which the electrical output of the rotor is dependent on both the shaft position and the electrical input to the stator.

**CONTROL UNIT** - In computers, that part which causes the arithmetic unit, storage, and transfer of a computer to operate in proper sequence.

**CONTROL WINDING** - Winding by means of which a controlling magnetomotive force is applied to a core.

**CONVERSION GAIN** - (1) Ratio of the IF output voltage to the input signal voltage of the first detector of a superheterodyne receiver. (2) Ratio of the available IF power output of a converter or mixer to the available RF power input.

**CONVERTER** - Section of a superheterodyne radio receiver which converts the desired incoming RF signal to a lower carrier frequency known as the intermediate frequency.

**CONVERTER TUBE** - Multielement vacuum tube used both as a mixer and an oscillator in a superheterodyne receiver. It creates a local frequency and combines it with an incoming signal to produce an intermediate frequency.

**COPPER-OXIDE RECTIFIER** - A metallic rectifier made of alternate layers of one or more discs or squares of copper on copper oxide.

**CORE** - (1) Magnetic material placed within a coil to change the intensity of the magnetic field. (2) Magnetic material inside a relay or inductor coil winding.

**CORNER** - Abrupt change in the direction of the axis of a waveguide.

**CORONA** - Luminious discharge due to ionization of the air surrounding a conductor around which exists a voltage gradient exceeding a certain critical value.

**COULOMB** - Measure of the quantity of electricity. One coulomb is equal to a current of 1 ampere flowing for 1 second; $6.28 \times 10^{18}$ electrons equal 1 coulomb.

**COULOMB'S LAW** - Law of electrostatic attraction. The force of attraction or repulsion between two charges of electricity concentrated at two points in an isotropic medium is proportional to the product of their magnitudes and is inversely proportional to the square of the distance between them.

**COUNTER** - Circuit which counts input pulses. One specific type is a circuit which produces one output pulse each time it receives some predetermined number of input pulses. The same term may also be applied to several such circuits connected in cascade to provide digital counting.

**COUNTER-ELECTROMOTIVE FORCE** - The effective electromotive force within the system which opposes the passage of current in a given direction.

**COUNTERPOISE** - A system of wires or other conductors, elevated above and insulated from the ground, forming a lower system of conductors of an antenna.

**COUNTING CIRCUIT** - Circuit which receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

**COUPLING** - Association of two circuits so that electrical energy may be transferred from one to the other.

**COUPLING CAPACITOR** - Capacitor used to couple two circuits together. Coupling is accomplished by means of capacitive reactance common to both circuits.

**COUPLING TRANSFORMER** - Transformer used to couple two circuits by means of mutual inductance.

**CRITICAL ANGLE** - Maximum angle at which a radio wave may be emitted from an antenna, in respect to the plane of the earth, and still be returned to the earth by refraction in the ionosphere.

**CRITICAL COUPLING** - Degree of coupling between two circuits independently resonant to the same frequency which results in maximum transfer of energy at the resonant frequency.

**CROSS MODULATION** - Cross modulation is unwanted modulation produced by one frequency altering, in some manner, another frequency. Cross modulation usually results from nonlinear circuits or overloading of equipment and generally causes crosstalk, either intelligible or unintelligible.

**CROSSTALK** - Unwanted sound reproduced by a given transmission channel resulting from cross coupling to another transmission channel, or, by extension, the electric waves in the disturbed channel which result in sound.

**CRYSTAL** - (1) Natural substance, such as quartz or tourmaline, which is capable of producing a voltage when under pressure or stress, or producing pressure when under an applied voltage. It has the property of responding only to a given frequency when cut to a given thickness. It is therefore a valuable medium to control the frequency of radio transmitters. (2) Nonlinear element, such as galena or silicon, in which case the piezoelectric characteristic is not exhibited.

**CRYSTAL CONTROLLED TRANSMITTER** - Radio transmitter whose carrier frequency is directly controlled by a crystal oscillator.

**CRYSTAL DETECTOR** - Mineral or crystalline material which allows electrical current to flow more easily in one direction than in the opposite, thus converting alternating current to pulsating current.

**CRYSTAL OSCILLATOR** - Oscillator circuit in which a crystal is used to control the frequency and to reduce frequency instability.

**CRYSTAL OVEN** - Container, maintained at a constant temperature, in which a crystal and its holder are enclosed in order to reduce frequency drift.

CRYSTAL RECTIFIER - Electrically conductive, or semiconductive substance, natural or synthetic, which has the property of rectifying voltages.

CURRENT - Drift of electrons past a reference point. The passage of electrons through a conductor. Measured in amperes.

CURRENT AMPLIFICATION - Ratio of output to input currents of an amplifier, or transducer.

CURRENT AMPLIFIER - Amplifier capable of delivering considerable current at a low voltage.

CURRENT SATURATION - Condition in which the current of a device cannot be further increased by increasing the voltage.

CUTOFF - Minimum value of bias which cuts off, or stops, the flow of tube current. In a transistor, when the output is no longer a function of the input and current is minimum.

CUTOFF LIMITING - Limiting a signal by driving an amplifier beyond cutoff.

CYCLE - (1) One complete positive and one complete negative alternation of an alternating current. (2) Complete set of any recurrent values.

CYCLE PER SECOND - The number of cycles occurring in 1 second is called the frequency. Frequency is expressed in hertz (Hz).

DAMPED OSCILLATION - Oscillation which, because the driving force has been removed, gradually dies out, each cycle being smaller than the preceding, in smooth, regular decay.

DAMPED WAVE - A wave such that, at every point, the amplitude of each sinusoidal component is a decreasing function of the time.

DAMPING - (1) Reduction of energy in a mechanical or electrical system by absorption or radiation. (2) Act of reducing the amplitude of the oscillations of an oscillatory system; hindering or preventing oscillation or vibration; diminishing the sharpness of resonance of the natural frequency of a system.

D'ARSONVAL MOVEMENT - Meter movement commonly used in precision instruments for DC measurements. It consists essentially of a small, lightweight coil of wire supported on jeweled bearings between the poles of a permanent magnet. Spiral springs provide connections to the coil and keep the coil and its attached pointer at zero position on the meter scale. When the direct current to be measured is sent through the coil, its magnetic field interacts with that of the permanent magnet and causes rotation of the coil and pointer.

DATA - Plural term collectively used to designate material serving as a basis for discussion; material may or may not be technical in nature. The singular of data is datum.

DATA LINK - A communication link in which intelligence is represented by digital data rather than by literal means.

DATA PROCESSING - Operations performed on information to modify it in accordance with prescribed rules so it can be interpreted as required by a system.

DC AMPLIFIER - An amplifier capable of amplifying direct voltages. It generally employs, between stages, either resistive coupling alone, or resistive coupling combined with other forms of coupling.

DC GENERATOR - Rotating electrical machine that converts mechanical power into DC power.

DC PLATE RESISTANCE - Value or characteristic used in vacuum-tube computations. It is equal to the DC plate voltage divided by the DC plate current and is given the sign $R_p$.

DC RESISTANCE - Opposition offered by a circuit or body to the flow of direct current.

DEAD SHORT - Short circuit having minimum resistance.

**DECIBEL** - A dimensionless unit for expressing the ratio of two values, the number of decibels being 10 times the logarithm to the base 10 of a power ratio, or 20 times the logarithm of the base 10 of a voltage or current ratio. The abbreviation db is commonly used.

**DECIBELS ABOVE OR BELOW 1 MILLIWATT** - Unit used to describe the ratio of the power at any point in a transmission system to a referenced level of 1 milliwatt. The ratio expresses decibels above or below ths reference level of 1 milliwatt.

**DECOUPLING** - Preventing transfer or feedback of energy from one circuit to another.

**DECOUPLING CIRCUIT** - Circuit used to prevent interaction of one circuit with another.

**DECOUPLING NETWORK** - (1) Network which is used to prevent the interaction of two circuits. (2) Network of capacitors and chokes, or resistors, placed in leads which are common to two or more circuits to prevent unwanted and harmful interstage coupling.

**DEENERGIZE** - Stop the flow of current in a circuit, or remove the voltage from a circuit, as by opening a switch.

**DEFLECTING ELECTRODE** - An electrode, the potential of which provides an electric field to produce deflection of an electron beam.

**DEFLECTION** - Movement of the electron beam in a cathode-ray tube created by electromagnetic or electrostatic field, which are varied to cause the light spot to traverse the face of the tube in a predetermined pattern.

**DEFLECTION COILS** - Coils placed about the yoke of a cathode-ray tube to cause the displacement of the electron stream by the magnetic field produced within the tube as the result of current flowing through the coils.

**DEFLECTION FACTOR** - Reciprocal of the deflection sensitivity of a cathode-ray tube. It is, therefore, the amount of change in the deflecting field that will cause unit displacement of the electron beam at the screen. It may be expressed as volts per inch or deflecting coil current per inch.

**DEFLECTION PLATES** - Two pairs of parallel electrodes, the pairs set one forward of the other and at right angles to each other, parallel to the axis of the electron stream, within an electrostatic cathode-ray tube. An applied potential produces an electric field between each pair which, by varying the applied potential, may be varied to cause a desired angular displacement of the electron stream.

**DEFLECTION SENSITIVITY OF CATHODE-RAY TUBE** - Quotient of the displacement of the electron beam at the place of impact to the change in the deflecting field. Usually expressed in millimeters per volt applied between the deflection plates, or in millimeters per gauss of the deflecting magnetic field.

**DEFLECTION YOKE** - Assembly of one or more electromagnets to produce deflection of one or more electron beams.

**DEGASSING** - Process of driving out and exhausting any gases that are occluded in the electrodes and other parts of a vacuum tube and that would not be removed by evacuation alone.

**DEGAUSSING** - Demagnetizing

**DEGENERATION** - Process whereby a part of the output power of an amplifying device is returned to its input circuit in such a manner that it tends to cancel the input.

**DELAYED AUTOMATIC VOLUME CONTROL** - Automatic volume control circuit that acts only on signals above a certain strength. It thus permits reception of weak signals even though they may be fading, whereas normal automatic volume control would make the weak signals weaker. The delayed action is obtained by introducing a bias voltage that is in series with, and in opposition to the automatic volume control voltage.

**DELAYED SWEEP** - Sweep of the electron beam of a cathode-ray tube in which the beginning of the sweep is delayed for a time after the pulse which initiates the sweep.

**DELAY LINE** - Any device for producing a time delay of a signal.

**DELTA MATCHING TRANSFORMER** - An impedance device used to match the impedance of an open wire transmission line to an antenna. The two ends of the transmission line are fanned out so that the impedance of the line gradually increases. The ends of the transmission line are attached to the antenna at points of equal impedance, symmetrically located with respect to the center of the antenna.

**DEMODULATION DETECTION** - (1) A process wherein a wave resulting from previous modulation is employed to derive a wave having substantially the characteristics of the original modulating wave. (2) Process of extracting the signal intelligence from a modulated carrier wave.

**DEMODULATOR** - Device which operates on a carrier wave so as to recover the wave with which the carrier was originally modulated.

**DEPLETION LAYER** - In a semiconductor, a region in which the mobile-carrier charge density is insufficient to neutralize the net fixed charge density of donors and acceptors.

**DETECTION** - Process by which a wave corresponding to the modulating wave is obtained in response to a modulated wave.

**DETECTOR** - (1) Rectifier tube, crystal, or dry disc by which a modulation envelope on a carrier, or the simple on-off state of a carrier, may be made to drive a lower-frequency device. (2) Stage or circuit in a radio set that demodulates the RF signal into its audio or video component. (3) Receiver circuit which derives the desired sound from the modulated carrier wave.

**DETENT** - Stop or checking device, as a pin or lever on a ratchet wheel or similar device.

**DETUNE** - To adjust a circuit so that it is not resonant to an applied frequency.

**DEVIATION** - Term used in frequency modulation to indicate the amount by which the carrier or resting frequency increases or decreases when modulated.

**DIAMAGNETIC** - Magnetic permeability less than one and hence less than that of a vacuum. Examples are bismuth and antimony.

**DIELECTRIC** - Term applied to the insulating material between the plates of a capacitor. Air, paper, mica, and oil are dielectrics.

**DIELECTRIC CONSTANT** - Measure of that property of dielectric material that determines how much electrostatic energy can be stored per unit volume when voltage is applied. In effect, it is the ratio of the capacitance of a capacitor with a given dielectric to that of the same capacitor having a vacuum dielectric.

**DIELECTRIC LOSS** - Time rate at which electric energy is transformed into heat in a dielectric when it is subjected to a changing electric field.

**DIFFERENTIATING CIRCUIT** - Circuit which produces an output voltage substantially in proportion to the rate of change of the input voltage or current. Differentiating circuit employs time constants that are short compared to the duration of the pulse applied, thus differentiating the input pulse.

**DIFFUSE** - In all directions, not in any sharply defined path. Applicable to reflection, refraction, or transmission of light and other waves.

**DIFFUSED JUNCTION** - In a semiconductor device, a junction which has been formed by the diffusion of an impurity within a semiconductor crystal.

DIFFUSION CAPACITANCE - Of a semiconductor junction, the rate of change of stored minority-carrier charge with the voltage across the junction.

DIGITAL COMPUTER - A computer in which quantities are represented numerically and which can be used to solve complex problems. Electronic computers use either a decimal or binary system of notations.

DIGITAL DATA - Information expressed in numerical values based upon some particular base numbering system.

DIODE - A 2-electrode active device containing an anode and a cathode.

DIODE CLIPPER - See diode limiter.

DIODE DETECTOR - Diode used in a demodulation circuit.

DIODE LIMITER - Peak limiting circuit employing a diode that becomes conductive when signal peaks exceed a predetermined value.

DIODE MIXER - Diode in an RF line which mixes incoming radio frequency and local oscillator signals to produce an intermediate frequency.

DIODE RECTIFICATION - Half-wave rectification by means of a diode which depends on the fact that a diode passes current in one direction only.

DIODE SEMICONDUCTOR - A 2-electrode semiconductor device having an asymmetrical voltage-current characteristic.

DIPOLE ANTENNA - Straight radiator, usually fed at the center, producing a maximum of radiation in the plane normal to its axis. The length specified is the overall length. NOTE: Common usage in microwave antennas considers a dipole to be a metal radiating structure which supports a line current distribution similar to that of a thin, straight wire, a half wavelength long, so energized that the current has two nodes, one at each of the far ends.

DIRECT CURRENT - Unidirectional current which has an essentially constant average value.

DIRECTIONAL ANTENNA - Antenna which radiates or receives radio waves more effectively in some directions than others. The term is usually applied to antennas whose directivity is larger than that of a half-wave dipole.

DIRECTOR, ANTENNA - A parasitic antenna element of a directional array located in the general direction of the major lobe of radiation.

DISCHARGE - (1) Release of stored-up electricity. (2) In a storage battery, the conversion of the chemical energy of the battery into electric energy.

DISCHARGE TUBE - Any tube containing gas or vapor which is capable of being discharged by ionization.

DISCHARGING CURRENT - Current obtained by discharging a capacitor.

DISCRIMINATOR - (1) Device in which amplitude variations are derived in response to frequency or phase variations. (2) Part of a receiver circuit which removes the desired signal from an incoming FM carrier wave by changing modulations in terms of frequency variations into amplitude variation. (3) Circuit, the output voltage of which varies as a detector in an FM receiver.

DISTORTION - Undesired change in waveform.

DISTRIBUTED CAPACITANCE - Capacitance that exists between the turns in a coil or choke, or between adjacent conductors or circuits, as distinguished from the capacitance which is concentrated in a capacitor.

DISTRIBUTED INDUCTANCE - Inductance that exists along the entire length of a conductor, as distinguished from the inductance which is concentrated in an inductor.

**D-LAYER** - The lowest ionospheric layer. Its intensity is proportional to the height of the sun and is greatest at noon. Waves below approximately 3 MHz are absorbed by the D-layer when it is present. High angle radiation may penetrate the D-layer and be reflected by the E-layer.

**DONOR** - An impurity added to a crystal during manufacture to create a semiconductor. The donor transfers an electron to the conduction band.

**DOPING** - In a semiconductor device, a process of adding impurities to achieve desired characteristics.

**DOPPLER EFFECT** - (1) Phenomenon evidenced by the change in the observed frequency of a wave in a transmission system caused by a time rate of change in the effective length of the path of travel between the source and the point of observation. (2) Change, or apparent change, in a wavelength of sound, light, or other radiation when the source and the observer are in motion relative to one another.

**DOPPLER SHIFT** - Magnitude, in hertz, of the change in the observed frequency of a wave caused by the Doppler effect.

**DOSIMETER** - Instrument used to measure the radiation absorbed during a period of time.

**DOUBLE DIODE** - Vacuum tube (or semiconductor) having two diodes in the same envelope.

**DOUBLE-DIODE LIMITER** - Type of limiter which is used to remove all positive signals from a combination of positive and negative pulses, or to remove all the negative signals from such a combination of positive and negative pulses.

**DOUBLER** - Electronic circuit in which the output is tuned to twice the frequency of the input.

**DOUBLE-SIDEBAND TRANSMISSION** - Method of communication in which the frequencies produced by the process of modulation are symmetrically spaced both above and below the carrier frequency and are all transmitted.

**DOUBLE-SUPERHETERODYNE RECEPTION** - Method of reception in which two frequency converters are employed before final detection.

**DOUBLE-TUNED AMPLIFIER** - Amplifier of one or more stages in which each stage utilizes coupled circuits having two tuned circuits.

**DRIVEN-ELEMENT ANTENNA** - Antenna array element that receives power directly from the transmitter.

**DRIVER** - (1) Electronic circuit which supplies input to another electronic circuit. (2) Stage of amplification which precedes the power output stage.

**DROPOUT VOLTAGE OR CURRENT** - Of a magnetically operated device, the voltage (or current) at which the device will release to its deenergized position.

**DROPPING RESISTOR** - Resistor used to decrease a given voltage to a lower value.

**DRY CELL** - A cell in which the electrolyte exists in the form of a jelly, or is absorbed in a porous medium, or is otherwise restrained from flowing from its intended position. Such a cell is completely portable and the electrolyte is nonspillable.

**DRY-ELECTROLYTIC CAPACITOR** - Electrolytic capacitor in which the electrolyte is in paste, rather than liquid form.

**DUMMY ANTENNA** - A device which has the necessary impedance characteristics of an antenna and the necessary power-handling capabilities, but which does not radiate or receive radio waves. NOTE: In receiver practice, that portion of the impedance not included in the signal generator is often called dummy antenna.

**DUTY CYCLE** - (1) Cycle of starting, running, and stopping operations that a motor or other equipment of intermittent duty performs. (2) Ratio of pulse duration time to pulse repetition time, which is the same as the ratio of average power to peak power in a pulse.

**DYNAMIC CHARACTERISTICS** - Relation between the instantaneous plate voltage and plate current of a vacuum tube as the voltage applied to the grid is increased or decreased.

**DYNAMIC LOUDSPEAKER** - Loudspeaker in which the coil carrying the AF current is attached to the moving diaphragm or core.

**DYNAMIC PLATE RESISTANCE** - Opposition that the plate circuit of a vacuum tube offers to a small increment of plate voltage. It is the ratio of a small change in plate voltage to the resulting change in the plate current, other tube voltages remaining constant. Dynamic plate resistance is usually designated by $r_p$ and is expressed in ohms.

**DYNAMO** - Machine for converting mechanical energy into electrical energy generally called a generator. The term dynamo more often applies to a DC generator, while alternator applies to an AC generator.

**DYNAMOTOR** - Combination electric motor and DC generator having two or more separate armature windings and a common set of field poles. One armature winding receiving direct current operates as a motor producing rotation, while the others operate as a dynamo or generator, generating voltage. More simply a rotating device used to change on DC voltage to a different DC voltage.

**DYNATRON** - Four-electrode vacuum tube so designed that secondary emission of electrons from the plate causes the plate current to decrease as plate voltage is increased giving a negative resistance characteristic. Used in oscillator circuits.

**DYNODE** - One of the reflecting electron mirrors in a multiplier-type phototube. It is coated with a material capable of high second emission.

**ECHO** - Wave which has been reflected or otherwise returned with sufficient magnitude and delay to be perceived, in some manner, as a wave distinct from the directly transmitted.

**EDDY CURRENT** - Currents induced in the body of a conducting mass by a variation of magnetic flux.

**EFFECTIVE VALUE** - Alternating-current value that will produce the same amount of heat in a resistance as the corresponding direct-current value. The effective value is also called the RMS (root mean square) value. It is 0.707 times the peak value for a sine wave.

**EFFICIENCY** - Total output power divided by total input power.

**E-LAYER** - One of the regular ionospheric layers with an average height of about 100 kilometers. This layer occurs during daylight hours and its ionization is dependent on the sun's angle. The principal layer corresponds roughly to what was formerly called the Kennelly-Heaviside layer. In addition, areas of abnormally intense ionization frequently occur which are called "sporadic E."

**ELECTRICAL CHARGE** - Symbol Q, q. The quantity of electricity on (or in) a body is the excess of one kind of electricity over the other kind. A plus sign indicates that the positive electricity is in excess, a minus sign indicates that the negative electricity is in excess.

**ELECTRICAL LENGTH** - Length expressed in wavelengths, or angular units. When expressed in angular units, it is the distance in wavelengths multiplied by $2\pi$ to give radians or by 360° to give degrees.

**ELECTRIC ANGLE** - Means of specifying a particular instant in an AC cycle. One cycle is considered equal to 360°, hence a half cycle is 180° and a quarter cycle is 90°. If one voltage reaches a peak value a quarter of a cycle after another, the electrical angle between the voltages (the phase difference) is 90°.

**ELECTRIC BREAKDOWN** - Electric discharge taking place through an insulating material.

**ELECTRIC FIELD** - (1) Region around an electrically-charged body wherein lines of electric stress exist. (2) Space in which an electric charge will experience a force exerted upon it.

**ELECTRICITY** - Property of certain particles to possess a force field which is neither gravitational nor nuclear. The type of field force associated with electrons is defined as negative and that associated with protons and positrons as positive. The fundamental unit is the charge of an electron: $1.60203 \times 10^{-19}$ coulomb. Electricity can be further classified as static electricity or dynamic electricity. Static electricity in its strictist sense refers to charges at rest as opposed to dynamic electricity, or charges in motion.

**ELECTRODE** - (1) Terminal at which electricity passes from one medium into another. (2) Of a semiconductor device, an element that performs one or more of the functions of emitting or collecting electrons or holes, or of controlling their movements by an electric field. (3) In a vacuum tube, the conducting element that performs one or more of the functions of emitting, collecting, or controlling electrons.

**ELECTRODE VOLTAGE OR POTENTIAL** - Voltage between an electrode and the cathode.

**ELECTROLYTE** - Any substance whose solutions have the property of conducting electric current.

**ELECTROLYTIC CAPACITOR** - Capacitor which is comprised of two plates separated by electrolyte. Under the action of the applied DC voltage, a film of hydrogen gas is formed on one plate, and it is this film which acts as the dielectric. This type of construction makes it possible to concentrate large values of capacitance in a relatively small space.

**ELECTROMAGNET** - An electrically excited magnet capable of exerting mechanical force, or of performing mechanical work.

**ELECTROMAGNETIC COUPLING** - Coupling that exists between circuits when they are mutually affected by the same electromagnetic field.

**ELECTROMAGNETIC DEFLECTION** - Beam control of the electron beam in a cathode-ray tube by magnetic circuit. Pairs of coils are mounted on the neck of the tube outside of the glass envelope and excited by voltages applied in such a manner that a sawtooth wave of current flows through the coils. The varying magnetic field deflects the beam.

**ELECTROMAGNETIC ENERGY** - Forms of radiant energy, such as radio waves, heat waves, light waves, X-rays, gamma rays, and cosmic rays.

**ELECTROMAGNETIC FIELD** - (1) Field of influence which an electric current produces around the conductor through which it flows. (2) Rapidly moving electric field and its associated magnetic field located at right angles to both electric lines of force and to their direction of motion. (3) Magnetic field resulting from the flow of electrons.

**ELECTROMAGNETIC FOCUSING** - The use of magnetic coils in a CRT to direct a magnetic or magnetostatic focusing field on the electron beam.

**ELECTROMAGNETIC INDUCTION** - Production of a voltage in a coil due to a change in the number of magnetic lines of force (flux linkages) passing through the coil.

**ELECTROMAGNETIC RADIATION** - Emission of energy in the form of electromagnetic waves. The term is also used to describe the radiated energy.

**ELECTROMAGNETIC WAVE** - (1) Transverse wave associated with the transmission of electromagnetic energy. (2) Wave produced by the oscillation of an electric charge. (3) Wave in which there are both electric and magnetic displacements. (4) Electromagnetic waves are known as radio waves, heat rays, light rays, X-rays, etc., depending on the frequency.

**ELECTROMOTIVE FORCE** - Property which tends to alter the motion of electricity or to maintain its motion against resistance. Difference of electrical potential or pressure, measured in volts.

**ELECTRON** - Elementary negative charge that revolves around the nucleus of an atom.

**ELECTRON-COUPLED OSCILLATOR** - An oscillator employing a multigrid tube in which the cathode and two grids operate in a conventional manner as an oscillator and in which the plate circuit load is coupled to the oscillator through the electron stream.

**ELECTRON DRIFT** - Actual movement of electrons in a definite direction through a conductor during current flow, as contrasted with transfer of energy from one electron to another by collision.

**ELECTRON EMISSION** - Liberation of electrons from the surface of a body into space under the influence of heat, light, impact, chemical disintegration, or a potential difference.

**ELECTRON GUN** - An electrode structure which produces and may control focus, deflect, and converge one or more electron beams.

**ELECTRON EFFICIENCY** - The ratio of the power at the desired frequency, delivered by the electron stream to the circuit in an oscillator or amplifier, to the average power supplied to the stream.

**ELECTRONICS** - Branch of science which deals with the motion, conversion, and behavior of electrons.

**ELECTRON TUBE** - An electronic device in which conduction takes place by electrons moving through a vacuum or gaseous medium with a gas-tight envelope.

**ELECTROSTATIC** - Pertaining to electricity at rest, such as charges on an object (static electricity).

**ELECTROSTATIC CHARGE** - Electric charge stored in a capacitor or on the surface of an insulated object.

**ELECTROSTATIC DEFLECTION** - Deflecting an electron beam by applying a voltage between plates mounted inside a cathode-ray tube.

**ELECTROSTATIC FIELD** - Field of force (influence) between two electrically charged bodies.

**ELECTROSTATIC FOCUS** - Production of a focused electron beam in a cathode-ray tube by the application of an electric field.

**ELECTROSTATIC SHIELD** - Shield used to prevent electrostatic coupling between circuits but which permits electromagnetic coupling.

**ELEMENT** - (1) Substance, in chemistry, that cannot be divided into simpler substances by any means ordinarily available. (2) Radiator, active or parasitic, that helps make up an antenna. (3) Element or finished element is sometimes applied as a synonym of oscillator plate. (4) Of a semiconductor device, any integral part of the semiconductor device that contributes to its operation.

**EMISSION** - (1) Radio waves radiated into space by a radio transmitter. (2) Process of ejecting electrons from the surface of a material under the influence of heat, radiation, or other causes.

**EMITTER** - Of a transistor, a region from which charge carriers that are minority carriers in the base are injected into the base.

**EMITTER JUNCTION** - Of a transistor, a junction normally biased in the low-resistance direction to inject minority carriers into a base.

**ENABLING PULSE** - A pulse which prepares a circuit for some subsequent action.

**END-FIRE ARRAY** - A driven antenna array in which the elements are parallel and in the same plane. The elements are excited so that the currents are out of phase. Maximum radiation occurs along the plane of the elements.

**ENERGIZE** - Supply power necessary to provide normal and effective operation (such as with transmitters, receivers, relays, and other equipment).

**ENERGY GAP** - Of a semiconductor, the energy range between the bottom of the conduction band and the top of the valence band.

**ENVELOPE** - (1) Glass or metal housing of a vacuum tube. (2) Curve drawn to pass through the peaks of a graph showing the waveform of a modulated radio-frequency carrier signal.

**EQUIVALENT CIRCUIT** - An electrical circuit, usually drawn, which is electrically equivalent to another electrical circuit or mechanical device. The equivalent circuit is used for analysis of complex circuits. In transistor design and study, the equivalent circuit makes it possible to easily analyze transistor action.

**ERROR SIGNAL** - Signal, in an automatic control device, whose magnitude and sign are used to correct the alignment between the controlling and the controlled elements.

**E-WAVE** - Designation of transverse magnetic waves. One of the two classes of electromagnetic waves that can be sent through waveguides.

**EXCESS ELECTRON** - An electron introduced into a semiconductor by a donor impurity and available to promote conduction. An excess electron is not required to complete the bond structure of the semiconductor.

**EXCITATION** - (1) Electrical energy which, when applied to a device, causes that device to produce an effect. (2) In electric or electromagnetic equipment, supplying with potential, a charge, or a magnetic field. (3) The addition of energy to a system so as to transfer it from its ground state to an excited state.

**EXCITER** - (1) Part of a directional transmitting antenna system which is directly connected to the source of power, as to the transmitter. (2) Crystal oscillator or self-excited oscillator that generates the carrier frequency of a transmitter. (3) Small auxiliary generator that provides field currents for generator.

**EXCLUSIVE OR CIRCUIT** - Circuit that produces an output signal when any one, but not more than one, input is in its prescribed state.

**EXPONENTIAL** - Pertaining to exponents or to an expression having exponents. A quantity varying in an exponential manner is increasing according to the square, or some other power, of a factor instead of linearly.

**EXTERNAL RESISTANCE** - Resistance that is connected externally between the terminals of a battery or generator.

**EXTINCTION POTENTIAL** - Lowest value to which the plate voltage of a gaseous tube can be reduced from a higher value under given conditions without stopping the flow of plate current.

**FACTOR** - Elements, quantities, or symbols which, when multiplied together, form a product.

**FARAD** - Basic unit of capacitance. A capacitor has a capacitance of 1 farad when a voltage change of 1 volt per second across it produces a current of 1 ampere.

**FARADAY SHIELD** - Network of parallel wires connected to a common conductor at one end to provide electrostatic shielding without affecting electromagnetic waves. The common conductor is usually grounded.

**FEEDBACK** - Method of regeneration or degeneration involving a coupling where a signal is fed from a high level point in an amplifier to a lower level point in the same or a previous stage in such a manner as either to increase or to decrease the apparent gain of the amplifier.

**FERROMAGNETIC MATERIAL** - Highly magnetic material, such as iron, cobalt, nickel, or alloys, make up these materials.

**FERROMAGNETISM** - Magnetism exhibited by ferrites and similar substances wherein neighboring ions in the presence of a magnetic field align themselves antiparallel. Since the magnetic moments of neighboring ions may be different in magnitude, the effective magnetization can be quite large.

**FIDELITY** - Synonym for lack of waveform distortion. Used to denote the accuracy with which a waveform is duplicated after having passed through a transmission system or portion thereof. Fidelity, however, as the word is commonly used, is not affected by waveform impairment due to the introduction of interference.

**FIELD COIL** - A suitable insulated winding to be mounted on a field pole to magnetize it.

**FIELD DENSITY** - In a particular cross-sectional area of a magnetic or electric field, the number of magnetic or electric lines of force or the magnetic or electric flux passing through it.

**FIELD EFFECT TETRODE** - Four-terminal device consisting of two independently terminated semiconducting channels so displaced that the conductance of each is modulated along its length by the voltage conditions in the other.

**FIELD EFFECT TRANSISTOR** - Transistor that uses charge carriers of only one polarity. The input signal modulates a transverse electric field to vary the effective cross-sectional area of the semiconductor, thereby varying the resistance that controls output current.

**FIELD EFFECT VARISTOR** - Passive 2-terminal nonlinear semiconductor device that maintains constant current over a wide voltage range.

**FIELD EMISSION** - The emission of electrons from unheated surfaces, produced by sufficiently strong electric fields.

**FIELD INTENSITY** - Electric or magnetic field intensity at a given location associated with the passage of radio waves. It is commonly expressed in terms of electric field intensity, in microvolts, millivolts, or volts per meter. In the case of a sinusoidal wave, the root-mean-square value is commonly stated. Unless otherwise stated it is taken in the direction of maximum field intensity.

**FIELD OF FORCE** - Term used to describe the total force exerted by an action-at-a-distance phenomenon such as gravity upon matter, electric charges acting upon electric charges, magnetic forces acting upon other magnets or magnetic materials.

**FILAMENT** - A cathode of a thermionic tube, usually in the form of a wire or ribbon, to which heat may be supplied by passing current through it.

**FILTER** - Network of resistors, inductors, and capacitors, or any one or two of these, which offers comparatively little opposition to certain frequencies or to direct current, while blocking the passage of other frequencies.

**FIRING** - Of any gas or vapor filled tube, it is the process of gas ionization and the start of current flow.

**FIRST DETECTOR** - Circuit in a superheterodyne receiver in which the signal being received and the local-oscillator signal are combined to produce the IF signal.

**FIXED BIAS** - Bias voltage of constant value.

**FIXED CAPACITOR** - Capacitor having a definite capacitance value that cannot be adjusted.

**FIXED RESISTOR** - Resistor having a definite resistance value that cannot be adjusted.

**FLASHBACK VOLTAGE** - The inverse peak voltage at which ionization takes place in a gas tube.

**FLIP-FLOP** - (1) Device having two stable states and two input terminals (or types of input signals) each of which corresponds with one of the two states. The circuit remains in either state until caused to change to the other state by application of the corresponding signal. (2) A similar bistable device with an input which allows it to act as a single-stage binary counter.

**FLOATING GRID** - Vacuum-tube grid that is not connected to any circuit. It assumes a negative potential with respect to the cathode.

**FLOW** - Passage of electrons (a current) through a conductor or through space between electrodes.

**FLUORESCENT SCREEN** - Coating of fluorescent material on the inner face of a cathode-ray tube.

**FLUX** - (1) Material used to promote fusion or joining of metal in soldering, welding, or smelting. Rosin is widely used as a flux in electric soldering. (2) In electrical or electromagnetic devices, general term used to designate collectively all the electric or magnetic lines of force in a region.

**FLUX DENSITY** - Number of magnetic lines of force passing through a given area.

**FLYBACK** - (1) The shorter of the two time intervals comprising a sawtooth wave. (2) As applied to a cathode-ray tube, the return of the spot to its starting point after having reached the end of its trace. This portion of the wave is usually not seen because of blanking circuits.

**FLYWHEEL EFFECT** - The ability of a resonant circuit to operate continuously (because of energy storage) from short, constant phase and frequency pulses.

**FOCUS** - To make appropriate electrical adjustments in order to give a sharp image of sweep line or signals on the face of a cathode-ray tube.

**FOCUSING ANODE** - One of the electrodes in a cathode-ray tube, the potential of which may be varied to focus the electron beam. Varying the potential changes the electric field, and thereby alters the path of the electrons to change the spot size.

**FOCUSING ELECTRODE** - Electrode to which a potential is applied to control the cross-sectional area of the electron beam in a cathode-ray tube.

**FOLDED DIPOLE ANTENNA** - An antenna composed of two parallel, closely spaced dipole antennas, connected together at their ends with one of the dipole antennas fed at its center.

**FORWARD BIAS** - Bias applied to a semiconductor junction with polarity so that relatively high current flows through the junction.

**FORWARD CURRENT** - Current which flows upon application of forward voltage.

**FORWARD DIRECTION** - Of a semiconductor diode, the direction of lower resistance to the flow of steady direct current.

**FREE ELECTRONS** - Electrons which are not bound to a particular atom, and are free to move under the influence of an electric field.

**FREE-RUNNING MULTIVIBRATOR** - Multivibrator so arranged that it does not need a trigger pulse to start operation.

**FREE-RUNNING SWEEP** - Sweep triggered continously by an internal trigger generator.

**FREE SPACE** - Empty space with no free electrons or ions present. It has approximately the electrical constants of air.

**FREQUENCY** - (1) Of a periodic quantity in which time is the independent variable, the number of periods occurring in unit time. (2) Number of complete cycles existing in the form of a wave motion, such as alternating current or sound waves, per unit of time. When the time unit is 1 second, frequency is expressed in hertz.

FREQUENCY BAND - Continuous range of frequencies extending between two limiting frequencies.

FREQUENCY DISCRIMINATOR - A device in which amplitude variations are derived in response to frequency variations. If the device responds to variations in phase, it is known as a phase discriminator.

FREQUENCY DISTORTION - (1) Distortion which occurs as a result of failure to amplify or attenuate equally all frequencies present in a complex wave. (2) Impairment of fidelity introduced by a transducer as a result of the unequal transfer of frequencies (e.g., unequal amplification of frequencies within the passband of an amplifier).

FREQUENCY DOUBLER - A device whose output circuitry is resonant to the second harmonic of the input signal making the output frequency double that of the input.

FREQUENCY MODULATION - (1) The term "frequency modulation" means a system of modulation where the instantaneous amplitude of the modulating signal and the instantaneous radio frequency is independent of the frequency of the modulating signal. (2) Angle modulation in which the instantaneous frequency of a sine wave carrier is caused to depart from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave. NOTE: Combination of phase and frequency modulation is commonly referred to as frequency modulation.

FREQUENCY MULTIPLIER - (1) Device for delivering an output wave whose frequency is a multiple of the input frequency. Frequency doublers and triplers are special cases of frequency multipliers. (2) An amplifier circuit which amplifies a harmonic. Its output frequency is some multiple of the original frequency.

FREQUENCY PULLING - Frequency pulling of an oscillator is the change of the generated frequency caused by a change of load impedance.

FREQUENCY RANGE - Of a device, the frequency band over which the device is designed to operate.

FREQUENCY RESPONSE - Measure of effectiveness with which a circuit or device transmits the different frequencies applied to it.

FREQUENCY SHIFT KEYING - That form of frequency modulation in which the modulating wave shifts the output frequency between predetermined values, and the output wave has no phase discontinuity.

FREQUENCY TRIPLER - An amplifier, the output circuit of which is resonant to the third harmonic of the input signal. The output frequency is three times that of the input.

FRONT-TO-BACK RATIO - (1) Ratio of the resistance of a crystal to current flowing the normal direction to the resistance to current flowing in the opposite direction. A term used in connection with checking crystals used as mixers in microwave receivers. (2) Power ratio of a directional antenna between the front and rear ratio. (3) Ratio of signal strength transmitted in a forward direction to that transmitted in a backward direction. For receiving antennas, refers to the ratio of received signal strength when the signal source is in the front of the antenna to the received signal strength when the antenna is rotated 180°.

FULL-WAVE RECTIFIER - Rectifier arranged so that current is allowed to pass in the same direction to the load circuit during each half cycle of the alternating current supply.

FUNDAMENTAL FREQUENCY - Of a periodic quantity, the frequency of a sinusoidal quantity which has the same period as the periodic quantity.

FUSE - Protective device, used in an electric circuit, containing a wire, bar, or strip of fuisible metal. When the current increases beyond the rated strength of the fuse, the metal melts and the circuit is broken.

**FUSED JUNCTION** - In a semiconductor, a junction formed by a recrystallization on a base crystal from a liquid phase of one or more components and the semiconductor.

**GAIN** - Ratio of output to input voltage, current or power usually expressed in decibels. Gain and transmission gain are general terms used to denote an increase in signal power in transmission from one point to another. Gain is usually expressed in decibels and is widely used to denote transducer gain.

**GAIN CONTROL** - Control connected so that it can change the overall gain of an amplifier.

**GALVANOMETER** - An instrument for indicating or measuring a small electric current, or a function of the current, by means of a mechanical motion derived from electromagnetic or electrodynamic forces which are set up as a result of the current.

**GAMMA** - Forward current transfer ratio for a common collector configuration.

**GANG** - Couple mechanically two or more variable components (capacitors, switches, and potentiometers) to facilitate operation from a single control knob.

**GAS CURRENT** - Current flowing to an electrode and composed of positive ions which have been produced as a result of gas ionization by an electron current flowing between other electrodes.

**GASSINESS** - The presence of unwanted gas in a vacuum tube, usually in relatively small amounts, caused by the leakage from outside or evolution from the inside walls or elements of the tube.

**GAS TUBE** - An electron tube in which the contained gas or vapor performs the primary role in the operation of the tube.

**GATE** - (1) Circuit in which a signal (generally a square wave) switches another signal on or off. (2) Circuit having an output and one or more inputs so designed that the output is energized when and only when certain input conditions are met. (3) One of the electrodes in a field effect transistor. (4) To control the passage of pulse or signal.

**GAUSS** - The electromagnetic unit of magnetic induction. One gauss represents one line of flux per square centimeter.

**GENERATOR** - (1) Rotating machine which converts mechanical energy into electrical energy. (2) Radio device which develops an AC voltage at a desired frequency and of a desired shape when energized with DC power. (3) Any device which generates electricity.

**GERMANIUM DIODE** - Rectifier or detector using metallic germanium crystal.

**GETTER** - Alkali metal introduced into a vacuum tube during manufacture and fired after the tube has been evacuated to react chemically with any gases which may have been left in manufacturer. The silvery deposit on the inside of the glass envelope of a tube, usually near the tube base, is the result of getter firing.

**GIGA** - A prefix indicating that the unit is raised to the ninth power of 10. Thus 1 gigahertz is 1 billion hertz.

**GILBERT** - Unit of magnetomotive force in the centimeter-gram-second electromagnetic system. The value of the magnetomotive force in gilberts in any magnetic circuit is equal to the line integral around the circuit of the magnetic intensity when the magnetic intensity is expressed in oersteds with length being in centimeters. One gilbert is equivalent to 0.7956 ampere turns.

**GLOW-DISCHARGE VOLTAGE REGULATOR** - Gas tube that varies in resistance, depending on the value of the applied voltage. It is used for voltage regulation.

**GLOW LAMP** - One in which light is produced by a glow discharge between two electrodes in an evacuated envelope into which a small quantity of gas or vapor has been introduced. It does not provide rectification. Neon gives a reddish-orange glow, mercury vapor gives a blue glow, and argon gives a purple glow.

**GRAPH** - Pictorial presentation of the relation between two or more variable quantities, such as between an applied voltage and the current it produces in a circuit.

**GRID BIAS** - Direct-current voltage between the grid and the cathode of an electron tube.

**GRID BLOCKING** - Blocking of capacitance-couple stages in an amplifier caused by the accumulation of charge on the coupling condensers due to grid current passed during the reception of large signals.

**GRID CAPACITOR** - Capacitor which is connected in series with the grid lead of an electron tube.

**GRID CIRCUIT** - Circuit connected between the grid and cathode of a vacuum tube, forming the input circuit of the tube.

**GRID EMISSION** - Electron or ion emission from a grid of an electron tube.

**GRID LEAK** - A high resistance connected across the grid-input capacitor or between the grid and the cathode to provide a DC path from grid to cathode and to limit the accumulation of charge on the grid.

**GRID-LEAK DETECTOR** - Triode or multielectrode tube in which rectification occurs because of electron current to the grid. The voltage associated with this flow through a high resistance in the grid circuit appears in amplified form in the plate circuit.

**GRID LIMITING** - A limiter circuit which operates by limiting positive grid voltages by means of a large ohmic value resistor. As the exciting signal moves in a positive direction with respect to the cathode, current through the resistor causes an IR drop which holds the grid voltage essentially at cathode potential. During negative excursions, no current flows in the grid circuit; so no voltage drops occurs across the resistor.

**GRID RESISTOR** - General term used to denote any resistor in the grid circuit.

**GRID SUPPRESSOR** - A resistor of low ohmic value (50 to 100 ohms), sometimes inserted in the grid circuit of an RF amplifier to prevent parasitic oscillations.

**GRID SWING** - Total variation in grid-cathode voltage from the positive peak to the negative peak of the applied signal voltage.

**GRID VOLTAGE** - Voltage between a grid and the cathode measured at the electron tube terminals.

**GROUNDED** - Connected to earth or to some conducting body which serves in place of earth.

**GROUNDED-GRID AMPLIFIER**- An electron-tube amplifier circuit in which the control grid is at ground potential at the operating frequency, with input applied between cathode and ground, and the output load connected between plate and ground. The grid-to-plate impedance of the tube is in parallel with the load instead of acting as a feedback path.

**GROUND POTENTIAL** - Zero potential with respect to the ground or earth.

**GROUND WAVE** - Radio wave that is propagated over the earth. A ground wave includes all components of a radio wave over the earth except ionospheric and tropospheric waves.

**GROWN SEMICONDUCTOR** - A junction produced during growth of the crystal during a melt.

**HALF-WAVE ANTENNA** - An antenna whose length is approximately equal to one-half the wavelength being transmitted or received.

**HALF-WAVE RECTIFIER** - A nonlinear device used to rectify alternating current into direct current. Only one-half of the input cycle is rectified, the output wave being a pulsating direct current.

**HARD TUBE** - High-vacuum electronic tube.

**HARMONIC** - Integral multiple of a fundamental frequency; e.g., harmonics of 60 hertz are 120 hertz, 180 hertz, 240 hertz, etc.

**HARMONIC CONTENT** - Degree of distortion in the output signal of an amplifier.

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**HARMONIC DISTORTION** - Production of harmonic frequencies at the output by the nonlinearity of a transducer when a sinusoidal voltage is applied to the input. Amplitude of distortion is usually a function of the amplitude of the input signal.

**HARMONIC GENERATOR** - Vacuum tube or other generator operated under conditions in which it generates RF current having strong harmonics.

**HARTLEY OSCILLATOR** - An oscillator in which a parallel-tuned tank circuit is connected between grid and plate or base and collector, the inductive element of the tank having an intermediate tap at cathode or emitter potential.

**HEATER** - An electric heating element for supplying heat to an indirectly heated cathode.

**HEAT SINK** - Mass of metal that is added to a device, such as a power transistor to absorb or dissipate heat.

**HEAVISIDE LAYERS** - Layers of ionized gas, existing in the region between 50 and 400 miles above the surface of the earth, which bend some frequencies of radio waves back to earth under certain conditions.

**HENRY** - Centimeter-gram-second electromagnetic unit of inductance or mutual inductance. The inductance of a circuit is 1 henry when a current variation of 1 ampere per second induces 1 volt. It is the basic unit of inductance. In radio smaller units are used, such as the millihenry (mh), which is one-thousandth of a henry (H), and the microhenry ($\mu$h), which is one-millionth of a henry.

**HEPTODE** - Seven-electrode vacuum tube containing an anode, a cathode, a control electrode, and four additional electrodes, usually grids.

**HERTZ** - Unit of frequency equal to 1 cycle per second.

**HETERODYNE** - (1) Process of combining two signal frequencies in a nonlinear device, with the result that frequencies equal to the sum and difference of the combining frequencies are produced. (2) To beat or mix two frequencies in a nonlinear component in order to produce different frequencies from those introduced.

**HETERODYNE DETECTION** - Detection (or conversion) by means of the heterodyne principle; used in the generation of the intermediate frequency of a superheterodyne receiver and in making CW signals audible.

**HETERODYNE DETECTOR** - Detector, incorporating a local oscillator (called a beat-frequency oscillator), used to convert an incoming RF signal to an audible tone by the heterodyne process.

**HEXODE** - Six-electrode vacuum tube containing an anode, a cathode, a control electrode, and three additional electrodes, usually grids.

**HIGH FIDELITY** - Term applied to an audio component, amplifier, or system. Ideally, it is the ability to reproduce faithfully; that is with a minimum of distortion, the full audio range of frequencies. While no universal standard has been set up, this range is generally agreed to be approximately 20 to 20,000 hertz. However, the term is often loosely applied to units whose range falls short of these limits.

**HIGH-LEVEL MODULATION** - Modulation produced at a point in a system where the power level approximates that at the output of the system; it is also called plate modulation.

**HIGH-MU TUBES** - Tubes having a very high amplification factor.

**HIGH-PASS FILTER** - Selective transducer which efficiently passes waves of all frequencies down to a certain frequency (cutoff frequency) and effectively bars waves having frequencies lower than the cutoff frequency.

**HIGH Q** - High ratio of reactance to effective resistance. It is an expression of coil efficiency.

**HIGH RESISTANCE VOLTMETER** - Voltmeter having a resistance considerably higher than 1000 ohms per volt, so that it draws very little current from the circuit in which a measurement is made.

**HIGH-VACUUM RECTIFIER** - Vacuum-tube rectifier in which conduction is entirely by electrons emitted from the cathode.

**HIGH-VACUUM TUBE** - Electron tube evacuated to such a degree that its electrical characteristics are essentially unaffected by gaseous ionization.

**HOLE** - A mobile vacancy in the electronic valence structure of a semiconductor which acts as a positive electronic charge with a mass.

**HOLE CURRENT** - The current in a semiconductor associated with apparent positive charges designated as holes.

**HOOD** - Shield used with a cathode-ray tube to eliminate extraneous light and thus make the image on the screen appear clear.

**HORIZONTAL** - (1) Perpendicular to the direction of gravity. (2) In the direction of, or parallel to, the horizon. (3) On a level.

**HORIZONTALLY POLARIZED WAVES** - Linearly polarized electromagnetic wave whose direction of polarization is horizontal. A horizontally polarized wave is one in which the electric intensity is parallel to the earth.

**HORN** - (1) Tube of varying cross-sectional area for radiating or receiving acoustic waves. (2) Primary element consisting of a part of a metal waveguide in which one or both cross-sectional dimensions increase toward the open end.

**HORN MOUTH** - End of the horn with the larger cross-sectional area.

**HORN THROAT** - End of the horn with the smaller cross-sectional area.

**HORSESHOE MAGNET** - Permanent magnet or electromagnet bent into the shape of a horseshoe or having a U-shape to bring the two poles near each other.

**HOT** - (1) Connected, alive, energized; pertains to terminal or any ungrounded conductor. (2) Not grounded.

**HOT-WIRE AMMETER** - Instrument in which current is measured by sending it through a fine wire, which is thereby heated. The resulting expansion or sag of the wire is used to deflect the meter pointer. It can be used to measure either alternating current or direct current, since both have the same heating effect, but is used chiefly at radio frequencies.

**HUM** - In audio-frequency systems, a low-pitched droning noise, usually composed of several harmonically related frequencies, resulting from an AC power supply, from ripple from a DC power supply, or from induction due to exposure to a power system. By extension, the term is applied in visual systems to interference resulting from similar sources.

**HUNTING** - (1) Servos and radar: mechanical oscillation in a servosystem due to improper adjustment of control voltage, servoamplifier, or feedback. (2) Motors: synchronous motor is said to hunt when it tends to drive ahead of a synchronous speed, then fall back several times a second (for small motors). The average speed of the motor is not affected unless the hunting causes the motor to fall out of synchronism.

**H-WAVE** - Mode in which electromagnetic energy can be transmitted in a waveguide. An H-wave has an electric field which is entirely transverse (perpendicular to the length of the waveguide) and a magnetic field which has a longitudinal component in addition to its transverse component.

**HYSTERESIS** - The phenomenon exhibited by a system or device whose state depends on its previous history. The term is generally used to refer to magnetic hysteresis, as hysteresis may generate excessive heat. Electric hysteresis occurs in dielectrics, and elastic hysteresis in solids.

**HYSTERESIS LOOP** - Hysteresis loop for a magnetic material in a cyclicly magnetized condition is a curve (usually with rectangular coordinates) showing two values of the magnetic induction for each value of the magnetizing force, one when the magnetizing force is increasing, the other when it is decreasing.

**HYSTERESIS LOSS** - Power loss in an iron-core transformer or other alternating-current device due to a magnetic hysteresis.

**IDEAL DIELECTRIC** - Dielectric in which all the energy required to establish an electric field in the dielectric is returned to the source when the field is removed. A perfect dielectric must have zero conductivity. Also, all absorption phenomena must be lacking. A vacuum is the only known perfect dielectric.

**IDEAL TRANSFORMER** - Imaginary transformer which neither stores nor dissipates energy. It is a transformer having self- and mutual impedances which are pure inductances of infinitely great values and one which has a unit coefficient of coupling.

**IF** - (See INTERMEDIATE FREQUENCY.)

**IMAGE FREQUENCY** - (1) In heterodyne frequency converters in which one of the two sidebands produced by beating is selected, the image frequency is an undesired input frequency capable of producing the selected frequency by the same process. The word image implies the mirrorlike symmetry of signal and image frequencies about the beating oscillator frequency or the intermediate frequency, whichever is higher. (2) Carrier frequency of an undesired signal which is capable of combining with the frequency of the local oscillator in a superheterodyne, thus forming the intermediate frequency, and eventually being reproduced together with the desired signal. For example, if the intermediate frequency is 500 kilohertz, a locally generated signal of 5,500 kilohertz combined with signals of either 5000 kilohertz or 6000 kilohertz would result in the proper intermediate frequency. (3) In superheterodyne reception the image frequency is a radio frequency which is as far removed on one side from the intermediate frequency as the desired signal is on the other side.

**IMAGE RESPONSE** - Response of a superheterodyne receiver to the image frequency, as compared to the response to the desired frequency, usually expressed in decibels.

**IMPEDANCE** - Total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance; its symbol is Z.

**IMPEDANCE COUPLING** - A method of coupling using an impedance as the coupling device, common to both the primary and secondary circuits. This type of coupling is usually limited to audio systems, where high gain and limited bandpass are required.

**IMPEDANCE MATCHING** - Method of connecting a network or generator to a load so that there is a maximum transfer of power, or a minimum reflection. The two requirements are identical only when the impedance of the network to be matched is entirely resistive. When minimum, or zero reflection is desired, the load impedance is made equal to the network impedance; i.e., the load impedance is made the image of the network impedance with magneitude and phase angles equal, and the phase angles of the same sign as those of the generator network. For maximum power transfer, the load impedance must be conjugate of the network impedance; i.e., the magnitude and phase angle are equal but the phase angle is of the opposite sign to the network phase angle.

**IMPEDANCE-MATCHING TRANSFORMER** - Transformer used to obtain an impedance match between a source and load.

**IMPURITY** - Substance that, when diffused into semiconductor material in small amounts, either provides free electrons to the material or accepts electrons from it. Impurities that provide free electrons are called donors and cause the material to be N-type. Impurities that accept electrons and make "holes" are called acceptors and cause the material to be P-type.

**INCREMENT** - Change in the value of a variable.

**INDICATOR** - (1) That component of a set, such as a radar set, by which the data obtained by the set is presented for visual observation. Type of presentation is normally a cathode-ray indicator. (2) Lamps, switch positions, and other devices used to indicate a particular situation. (3) A part of a message. (4) A specific action which might signify the existence of a situation or condition.

**INDIRECTLY HEATED CATHODE** - A cathode of a thermionic tube to which heat is applied by an independent heater element.

**INDUCED** - Produced as a result of exposure of the influence or variation of an electric or magnetic field.

**INDUCED CHARGE** - Electrostatic charge produced on an object by the electric field that surrounds a nearby object.

**INDUCED CURRENT** - Current due to an induced voltage.

**INDUCED ELECTROMOTIVE FORCE** - The electromotive force induced in a conductor due to the relative motion between the conductor and a magnetic field.

**INDUCTANCE** - The property of an electrical circuit whereby changes in the current flowing in the circuit causes changes in the magnetic field associated with the circuit so that a counter EMF is set up, either in the circuit itself or in neighboring circuits. If the counter EMF is set up in the same circuit, it is self-inductance; if in a neighboring circuit, it is mutual inductance. The unit of inductance is the henry. The henry is the inductance which will induce a counter EMF of 1 volt when the inducing current is changed at a rate of 1 ampere per second. The henry is a large unit, and in radio work the henry is divided into smaller units, the millihenry (one-thousandth part) and the microhenry (one-millionth part).

**INDUCTANCE, DISTRIBUTED** - The inductance in a circuit which is not designed into the circuit but exists because of current flow. It is inherent in any circuit where current is flowing.

**INDUCTION** - (1) The establishment of an electric charge or a magnetic field in a substance by the proximity of an electrified source, a magnet, or a magnetic field. (2) The setup of an EMF and current flow in a conductor by variation of the magnetic field affecting the conductor.

**INDUCTION FIELD** - That portion of the electromagnetic field of a transmitting antenna which acts as if it were permanently associated with the antenna. The field near an antenna into which energy is alternately stored and removed. Energy of this type is not permanently lost to the antenna. (The radiation field leaves the transmitting antenna and travels through space as radio waves.)

**INDUCTIVE CIRCUIT** - Circuit containing a higher value of inductive reactance than capacitive reactance.

**INDUCTIVE FEEDBACK** - (1) Transfer of energy from the plate circuit to the grid circuit of a vacuum tube by means of induction. (2) Transfer of energy from the output circuit to the input circuit of an amplifying device through an inductor, or by means of inductive coupling.

**INDUCTIVE LOAD** - A reactive load that is predominantly inductive, so that the load current lags behind the load voltage.

**INDUCTIVE REACTANCE** - (1) Reactance which is caused by the inductance of a circuit. It is expressed in ohms and is equal to 2π times the product of the frequency in hertz and the inductance in henrys. (2) Opposition to the flow of alternating or pulsating current due to the inductance of a circuit. It dissipates no power, and its symbol is $X_L$.

**INDUCTOR** - (1) Device for introducing inductance into an electric circuit. (2) Coil having inductance.

**INERTIA** - Tendency for matter to remain at rest or if moving, to keep moving in the same direction.

**INFINITE LINE** - Transmission line having characteristics corresponding to those which would be obtained with an ordinary line that is infinitely long.

**INHIBIT-GATE** - Gate circuit whose output is energized only when certain signals are present and other signals are not present at the inputs.

**INITIATING** - Causing an action to start. A qualifying term applied to a device whose operation must precede that of other devices involved in an operating sequence.

**INJECTION GRID** - Grid introduced into a vacuum tube in such a way that it exercises control over the electron stream without causing interaction between the screen grid and control grid. The injection grid is used as a means of introducing the oscillator signal into the mixer stage in some superheterodyne receivers.

**IN-PHASE** - Condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

**INPUT** - (1) Current, voltage, power, or driving force applied to a circuit or device. (2) Terminals or other places where current, voltage, power, or driving force may be applied to a circuit or device.

**INPUT CAPACITANCE** - Sum of the interelectrode capacitances between the input electrode and all other electrodes except the output electrode.

> NOTE: This is not the effective capacitance, which is a function of the impedance of the associated circuit.

**INPUT IMPEDANCE** - Impedance presented by a device to the source.

**INPUT TRANSFORMER** - Transformer used to transfer energy from a voltage source to the input of a circuit or device.

**INSTANTANEOUS VALUE** - Magnitude at any particular instant of a value that is continually varying with respect to time.

**INSTRUMENT LANDING SYSTEM** - (ILS) A radio navigation system which provides aircraft with horizontal and vertical guidance just before and during landing and, at certain fixed points, indicates the distance to the reference point of landing.

**INSULATED WIRE** - Conductor covered with a nonconducting material.

**INSULATION** - (1) Nonconducting material used to prevent the leakage of electricity from a conductor and to provide mechanical spacing or support to protect against accidental contact. (2) Use of material in which current flow is negligible to surround or separate a conductor to prevent loss of current.

**INSULATOR** - (1) Material of such low conductivity that the flow of current through it can usually be neglected. (2) Device having high-electric resistance, used for supporting or separating conductors so as to prevent undesired flow of current from the conductors to other objects.

INTEGRATOR CIRCUIT - A circuit whose output waveform is substantially the time integral of its input waveform. NOTE: Such a circuit preceding a phase modulator makes the combination a frequency modulator; or, following a frequency detector, makes the combination a phase detector. Its ratio of output amplitude to input amplitude is inversely proportional to frequency, and its output phase lags its input phase by 90°.

INTELLIGENCE SIGNAL - Signal that conveys information.

INTENSITY - (1) Strength or amplitude of a quantity. (2) Relative strength of electric, magnetic, or vibrational energy. (3) The brilliance of an image on the screen of a cathode-ray tube.

INTENSITY MODULATION - Technique of applying a signal to the grid of a cathode-ray tube, so that the brightness of various portions of the pattern will be varied.

INTERCOMMUNICATIONS SYSTEM - Audio-frequency amplifier system that provides 2-way voice communications between two or more locations.

INTERELECTRODE CAPACITANCE - Capacitance existing between electrodes of a device.

INTERELECTRODE TRANSMIT TIME - Time required for an electron to traverse the distance between two electrodes.

INTERFERENCE - (1) Electrical disturbance which causes undesirable responses in electronic equipment. (2) Disturbance in radio reception caused by undesired signals, stray currents from electrical apparatus, etc. A current from a foreign source or a second communication line which in some way produces derogatory performance. Interference is sometimes spoken of as the current or power which causes noise in the telephone. (3) In a signal transmission system either extraneous power which tends to interfere with the reception of the desired signals, or the disturbance of signals which results.

INTERLOCK SWITCH - Safety switch which deenergizes high voltage when doors, access covers, or other openings are opened.

INTERMEDIATE FREQUENCY - (1) Fixed frequency to which all carrier waves are converted in a superheterodyne receiver. (2) Carrier frequency used in a stage of modulation intervening between the original signal and the final modulated carrier. (3) Frequency to which a signaling wave is shifted locally as an intermediate step transmission or reception. (4) Frequency resulting from the combination of the received signal and that of the local oscillator in a superheterodyne receiver.

INTERMEDIATE-FREQUENCY AMPLIFIER - Section of a superheterodyne receiver which amplifies intermediate frequency signals with high efficiency.

INTERMITTENT DEFECT - Defect that depends on varying conditions in a circuit and hence is not continuously present.

INTERNAL RESISTANCE - Resistance within a cell or battery to the flow of an electric current.

INTERROGATION SIGNAL - Signal sent out by an interrogator to a ship or aircraft whose identity is unknown.

INTERRUPTED CONTINUOUS WAVE - Continuous waves that are interrupted at a constant audio-frequency rate.

INTERSTAGE - Between stages.

INTRINSIC PROPERTIES - Of a semiconductor, the properties of a semiconductor that are characteristic of the ideal crystal.

INTRINSIC TEMPERATURE RANGE - In a semiconductor, the temperature range in which the electrical properties of a semiconductor are essentially not modified by impurities or imperfections within the crystal.

**INVERSE PEAK VOLTAGE** - (1) Peak value of the instantaneous voltage across a rectifier during the half of the cycle that it is not conducting. (2) The maximum voltage between cathode and plate of a vacuum tube when it is not conducting.

**INVERSE SQUARE LAW** - Law of optics which states that the intensity of light varies inversely as the square of the distance from the source of light. This is equally true of the intensity of a radio wave.

**INVERSE VOLTAGE** - The voltage impressed across a diode during the half cycle the anode is negative.

**INVERTER** - (1) Device for converting direct current into alternating current. (2) Circuit which takes in a positive pulse and puts out a negative one, or takes in a negative pulse and puts out a positive one.

**IONIZATION CURRENT** - Electric current resulting from the movement of electric charges in an ionized medium, under the influence of an applied electric field.

**IONIZATION POTENTIAL** - Potential at which ionization begins within a gas-filled tube. This potential is slightly lower than the firing or striking potential at which complete ionization takes place.

**IONIZE** - To make an atom or molecule of an element lose an electron, as by X-ray bombardment, and thus be converted into a positive ion. The freed electron may attach itself to a neutral atom or molecule to form a negative ion.

**IONOSPHERE** - An outer belt of the earth's atmosphere in which radiations from the sun or interstellar space ionize, or excite electrically, the atoms and molecules of the atmospheric gases. The height of the ionosphere varies with the time of day and the season, but its lower limit is generally considered to lie between 25 and 50 miles. It is divided into several layers with respect to radiation and reflective properties. A characteristic phenomenon is its reflection of certain radio waves.

**ION TRAP** - A method or device in manufacturing and operating cathode-ray tubes to prevent ions from bombarding the phosphor coating of the tubes and causing blemishes. The ions may be cathode-generated or generated by secondary emission of grid and cathode; they are heavier than electrons and are not deflected by the electron magnetic deflection circuits. The trap may be a bent-gun type, or straight-gun type, but an external magnetic field for control of the ions is required; i.e., external to the magnetic deflection circuits. An aluminized tube does not require an ion trap, nor does an electrostatically-focused and deflected tube require such a trap.

**IR DROP** - Voltage drop produced across resistance R by the flow of current I through the resistor.

**$I^2R$ LOSS** - Power loss in transformers, generators, connecting wires, and other parts of a circuit due to the flow of current I through resistance R of the conductors.

**IRON-CORE COIL** - Coil in which iron forms part or all of the magnetic core linking its windings.

**IRON-CORE TRANSFORMER** - Transformer in which iron forms part or all of the magnetic core linking the transformer windings.

**IRON LOSS** - Power loss occurring in iron cores of electric machines, coils, transformers, etc., due to hysteresis and eddy currents.

**JACK** - A connecting device to which a wire or wires of a circuit may be attached and which is arranged for the insertion of a plug.

**JUNCTION** - (1) Connection between two or more conductors or two or more sections of transmission lines. (2) Contact between two dissimilar metals or materials, as in a rectifier or thermocouple. (3) Meeting of two pole lines. (4) Point where the continuity of a pole line changes, as where a branch takes off. (5) Of a semiconductor, a transition region between semiconducting regions having different electrical properties, or between a metal and a semiconductor.

**JUNCTION TRANSISTOR** - A transistor having a base electrode and two or more junction electrodes.

**KEYER** - (1) device which changes the output of a transmitter from one condition to another in accordance with the intelligence to be transmitted. (2) Name often given to a radar modulator.

**KILOHERTZ** - Frequency of 1,000 hertz.

**KINETIC ENERGY** - Energy which a body possesses by virtue of its motion.

**KIRCHOFF'S LAWS** - (1) The algebraic sum of the currents flowing toward any point in an electric network is zero. (2) The algebraic sum of the products of the current and resistance in each of the conductors in any closed path in a network is equal to the algebraic sum of the electromotive forces in the path. These laws apply to the instantaneous values of currents and electromotive forces, but may be extended to the effective values of sinusoidal currents and electromotive forces by replacing algebraic sum by vector sum and by replacing resistance by impedance.

**KLYSTRON** - A special type of electron tube used as an oscillator or amplifier at UHF and SHF bands. A signal voltage on the grid varies the velocity of an electron stream rather than intensity as in a normal vacuum tube. Electrons emitted by a cathode are focused into a stream and directed into resonant cavities through gridlike apertures. An RF electric field set up between the apertures and parallel to the electron stream bunches the electrons by alternately increasing and decreasing their velocity. The resonant frequency may be varied by changing the electrode voltages, or by mechanical adjustment of the size and/or shape of the cavities.

**LAG** - Displacement in time, expressed in electrical degrees, between two waves of the same frequency, when the reference wave reaches its maximum value before the continued wave.

**LAGGING CURRENT** - Current flowing in a circuit which lags the voltage in the circuit.

**LAGGING LOAD** - A circuit load which causes the current to lag; predominately inductive rather than resistive or capacitive.

**LAMBDA** - Greek letter lambda ($\lambda$), generally used to designate wavelength.

**LAMINATED** - Made of thin layers.

**LAMINATED CORE** - Iron core for a coil, transformer, armature, etc., built up from laminations stamped from sheet iron or steel. The laminations are more or less insulated from each other by surface oxides and sometimes also by application of varnish. Laminated construction is used to minimize the effect of eddy currents.

**LANDLINE** - A communication cable on or under the earth's surface, in contrast to a submarine cable.

**LASER** - See LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION.

**LATTICE-WOUND COIL** - Coil wound in a crisscross manner to reduce distributed capacitance.

**LAW OF ELECTRIC CHARGES** - Like charges repel; unlike charges attract.

**LAW OF ELECTROMAGNETIC INDUCTION** (Faraday's law) - Electromotive force induced in a circuit is proportional to the time rate of change of the flux of magnetic induction linked with the circuit. When the change in flux linkage is caused by the motion, relative to a magnetic field, of a conductor forming a part of an electric circuit, the electromotive force induced in the circuit is proportional to the rate at which the conductor cuts the flux of magnetic induction.

**LAW OF ELECTROSTATIC ATTRACTION** (Coulomb's law) - Force of attraction or repulsion between two charges of electricity concentrated at two points in an isotropic medium is proportional to the product of their magnitudes and is inversely proportional to the square of the distance between them. The force between unlike charges is an attraction; between like charges a repulsion.

**LAW OF MAGNETISM** - Like poles repel; unlike poles attract.

**LAWS OF ELECTRIC NETWORKS** - See KIRCHHOFF'S LAWS.

**LC RATIO** - Ratio of L to C; equal to inductance in henrys divided by capacitance in farads.

**LEAD** - (1) Wire to or from a circuit or element. (2) Opposite of lag; to proceed.

**LEAD-ACID CELL** - Cell in an ordinary storage battery, in which electrodes are grids of lead containing an active material consisting of certain lead oxides that change in composition during charging and discharging. The electrodes or plates are immersed in an electrolyte of diluted sulfuric acid.

**LEADING CURRENT** - Current that reaches its maximum value before the voltage that produces it.

**LEADING LOAD** - Load that is predominately capacitive, so that its current leads the voltage applied to the load.

**LEAKAGE** - (1) Electrical loss resulting from poor insulation. (2) Undesired flow of electricity over or through insulators that are used to support or separate the conductors of a circuit. (3) That portion of a magnetic field which is not utilized most effectively.

**LEAKAGE CURRENT** - Stray current of relatively small value which flows through or across the surface of solid or liquid insulation when a voltage is impressed across the insulation. In transistors, flow of minority carriers caused by heat.

**LEAKAGE FLUX** - Magnetic lines of force that do not encircle all the turns in a coil or transformer and hence do not contribute to inductance or to the transfer of energy from one coil to another.

**LEAKY** - Condition in which the leakage resistance has dropped so much below its normal value that excessive leakage current flows. Usually applied to a capacitor.

**LEFT-HAND RULE** - (1) For a current-carrying wire, if the fingers of the left hand are closed around the wire so that the thumb points in the direction of electron flow, the fingers will be pointing in the direction of the magnetic field. (2) For generators; if the thumb, first, and second fingers of the left hand are extended at right angles to one another, with the thumb representing the direction of motion, the first finger representing the direction of the magnetic lines of force, the second finger points in the direction of flow. (For motors, use the right hand.)

**LENZ'S LAW** - Current induced in a circuit as a result of its motion in a magnetic field is in such a direction as to exert a mechanical force opposing the motion.

**LEVEL** - Difference of a quantity considered in relation to an arbitrarily specified reference value. Level may be stated in the units in which the quantity itself is measured (e.g., volts, ohms, etc.) or in units (e.g., db) expressing the ratio to a reference value.

**LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION** - (LASER) An active electronic device that converts input power into a very narrow, intense beam of coherent visible or invisible light.

**LIGHT-SENSITIVE** - Exhibiting a photoelectric effect when irradiated, such as photoelectric emission, photoconductivity, or photovoltaic action.

**LIMITER** - (1) Device in which some characteristic of the output is automatically prevented from exceeding a predetermined value; a transducer in which the output amplitude is substantially linear with regard to the input up to a predetermined value and substantially constant thereafter. (2) Stage or circuit commonly used in FM receivers that limits the amplitude of the signals to some predetermined maximum. In so doing, it limits interfering noise by removing excessive amplitude variations from signals. Limiters are also used in television and industrial electronic apparatus. NOTE: A limiter may be used to remove amplitude modulation while transmitting angle modulation.

**LINEAR** - Having an output which varies in direct proportion to the input.

**LINEAR AMPLIFICATION** - Amplification in which changes in output are directly proportional to changes in input.

**LINE OF FORCE** - Line used to represent an electric or magnetic field coinciding in direction with the field intensity at each point. When used as a unit of magnetic flux, a line of force is sometimes called a maxwell.

**LINE OF SIGHT** - (1) Distance to the horizon from an elevated point including the effects of atmospheric refraction. (2) Line of vision. (3) Straight line between an observer or radar antenna and a target. (4) Unobstructed or optical path between two points.

**LINE VOLTAGE** - Voltage level of main power supply to equipment.

**LINK COUPLING** - A modification of inductive coupling where the circuits are physically separated so there is no mutual inductance. A pair of coils furnishes the coupling.

**LISSAJOUS FIGURES** - Patterns produced on the screen of a cathode-ray tube by a combination of sine wave signal voltages of various amplitude and phase relations on horizontal and vertical deflection plates.

**LOAD** - (1) Power consumed by a device or circuit in performing its function. (2) Resistor or other impedance that can replace some circuit element that is to be temporarily or permanently removed. (3) To put data into a register or storage. (4) To place a magnetic tape reel on a tape drive, or to place cards into the card hopper of a card reader.

**LOAD IMPEDANCE** - Impedance presented by the load to the load circuit.

**LOAD LINE** - Straight line drawn across a family of characteristic curves to show how current will change with bias when a specified load resistance is used.

**LOBE** - (1) With reference to radiation patterns of antennas, a portion of the directional pattern bounded by one or two cones of nulls. (2) In connection with the radar coverage indicator, it is the pivoted plastic overlay representing the radiation pattern of the radar antenna.

**LOCAL OSCILLATOR** - A radio frequency oscillator within a superheterodyne radio receiver which generates a signal to heterodyne with the incoming signal to produce the intermediate frequency. The output of the local oscillator is fed to the mixer, and the IF output from the mixer may be either the sum or the difference of the incoming and local oscillator frequencies.

**LOGICAL DIAGRAM** - A diagram representing the logical elements and their interconnections without necessarily expressing construction details.

**LOGICAL ELEMENT** - In a computer or data-processing system, the smallest building blocks which can be represented by operators in an appropriate system of symbolic logic. Typical logical elements are the AND-gate and the flip-flop, which can be represented as operators in a suitable symbolic logic.

**LOGICAL SYMBOL** - In computers, a graphical symbol used to represent a logical element.

**LOOP ANTENNA** - Antenna consisting of one or more complete turns of a conductor, designed for directional transmission or reception.

**LOOSE COUPLING** - Degree of coupling less than the critical coupling.

**LOSS** - (1) Amount of electrical attenuation in a circuit, or the power consumed in a circuit component. (2) Energy dissipated in accomplishing useful work; usually expressed in db.

**LOWER SIDEBAND** - Lower of two frequencies or two groups of frequencies produced by an amplitude-modulation process.

LOW-LEVEL MODULATION - Modulation produced at a point in a system where the power level is low compared with the power level at the output of the system.

LOW-PASS FILTER - (1) Filter network which passes all frequencies below a specified frequency, with little or no loss, but which discriminates strongly against (attenuates) higher frequencies. (2) Wave filter having a single transmission band extending from zero frequency up to some critical or cutoff frequency, not infinite.

LUMPED CONSTANT - Single constant that is electrically equivalent to the total of that type of distributed constant existing in a coil or circuit.

MAGNET - Device or material which is the source of a magnetic field. Magnets may be artificial or natural. Artificial magnets may be electromagnets or permanent magnets.

MAGNETIC AMPLIFIER - Device using one or more saturable reactors, either alone or in combination with other circuit elements, to secure power gain.

MAGNETIC CORE - A form of computer storage using a magnetically permeable core.

MAGNETIC DEFLECTION - System using electromagnetic fields for the deflection of electron beams, as in cathode-ray tubes.

MAGNETIC DRUM - In SAGE, in a computer, a rapidly rotating cylinder with a ferromagnetic coating on which information is stored in the form of sequences of small spots corresponding to binary zero and one.

MAGNETIC FIELD - (1) Region in which the magnetic forces created by a permanent magnet or by a current-carrying conductor or coil can be detected. (2) A vector field of magnetizing force.

MAGNETIC FLUX DENSITY - Magnetic field intensity measured in gauss.

MAGNETIC LINES OF FORCE - Imaginary lines used for convenience to designate the direction in which magnetic forces are acting as a result of magnetomotive force.

MAGNETIC SATURATION - Condition in an iron core in which further increases in magnetizing force produce little or no increase in flux density of the core.

MAGNETIC SHIELD - Sheet or core of iron, enclosing instruments or radio parts to protect them from stray magnetic fields by providing a convenient path for the magnetic lines of force.

MAGNETISM - Property possessed by certain materials by which these materials can exert mechanical force on neighboring masses of magnetic materials; and can cause currents to be induced in conducting bodies moving relative to the magnetized bodies.

MAGNETIZATION CURVE - Curve plotted on a graph to show successive states during magnetization of a ferromagnetic material. A normal magnetization curve is a portion of a symmetrical hysteresis loop, while a virgin magnetization curve shows what happens the first time the material is magnetized.

MAGNETOMOTIVE FORCE - Force that is the cause of magnetic induction. It is the total magnetizing force acting around a closed magnetic circuit. If it results from the flow of current in a coil, it is proportional to the ampere-turn. The CGS unit of magnetomotive force is the gilbert (equal to about 0.8 ampere-turn).

MAGNETOSTRICTION - Expansion and contraction of a magnetic material under the influence of a varying magnetic field. Certain metals, notably nickel and some of its alloys, undergo dimensional changes when subjected to the influence of a magnetic field. These changes are minute—on the order of 1 part per million.

**MAGNETOSTRICTIVE FILTER** - A filter network which uses the magnetostrictive phenomena to form high-pass, low-pass, bandpass, or band-elimination filters. The impedance characteristic is the inverse of that of a crystal.

**MAGNETRON** - An electron tube, characterized by the interaction of electrons with the electric field of a circuit element in crossed steady electric and magnetic fields to produce AC power output. It is used to generate high power output in the UHF and SHF bands.

**MAJORITY CARRIER** - In semiconductors the type of carrier constituting more than half the total number of carriers. The majority carriers may be either holes or electrons, depending on the construction of the semiconductor.

**MANMADE INTERFERENCE** - Any electromagnetic interference due to the operation of electrical or electronic equipment, but particularly harmonic or spurious signals from RF devices, as opposed to noise.

**MARCONI ANTENNA** - Antenna system of which the ground is an essential part, as distinguished from a Hertz antenna.

**MARKER BEACON** - A transmitter in the aeronautical radio navigation service which radiates vertically a distinctive pattern for providing position information to aircraft.

**MASER** - See MICROWAVE AMPLIFICATION BY STIMULATED EMISSION OF RADIATION.

**MASTER OSCILLATOR** - (1) Oscillator which provides or controls modulator-drive frequencies for a number of channels or groups of channels. (2) Oscillator so arranged as to establish the carrier frequency of the output of an amplifier.

**MASTER-OSCILLATOR POWER AMPLIFIER** - Transmitter using an oscillator followed by one or more stages of RF amplification.

**MATCHED IMPEDANCE** - A load impedance placed across a network or source of energy so that there is either a maximum transfer of power or there are no reflections from the load.

**MATCHING STUB** - Device placed on a radio-frequency transmission line which varies the impedance of the line. The impedance of the line can be adjusted in this manner.

**MATCHING TRANSFORMER** - Transformer used for matching purposes.

**MATRIX** - In electronic computers: Any logical network whose configuration is a rectangular array of intersections of its input-output leads, with elements connected at some of these intersections. The network usually functions as an encoder or decoder; loosely, any encoder, decoder, or translator.

**MATTER** - Any physical entity which possesses mass.

**MAXWELL** - Centimeter-gram-second electromagnetic unit of magnetic flux. It is equal to 1 gauss per square centimeter, or to one magnetic line of force.

**MEDIUM** - Means for transmission of intelligence media; e.g., radio, wire, or cable, tropospheric scatter, microwave.

**MEG** - A prefix meaning 1 million, used in place of "mega" when preceding a vowel; e.g., "megohm."

**MEGA** - Other form of "meg." A prefix adopted by the National Bureau of Standards meaning 1 million or $10^6$.

**MEMORY** - See STORAGE.

**MERCURY CELLS** - Electrolytic cells having mercury cathodes with which the deposited alkali metal forms an amalgam.

**MERCURY-VAPOR RECTIFIER** - A rectifier tube which has had mercury added to the envelope. When heated by the filament current, the mercury vaporizes, and this vapor is ionized by the positive plate voltage. Mercury vapor rectifiers have a low internal voltage drop, which is constant and not dependent on the current passed by the tube.

**METER** - (1) Unit of length in the metric system of measurement. One meter is equal to 39.37 inches, 3.281 feet, or 1.094 yards in English units of length. (2) Term used to designate any type of measuring device including all types of electrical measuring instruments.

**MHO** - Unit of conductance or admittance; the reciprocal of the ohm.

**MICRO** - Prefix adopted by the National Bureau of Standards meaning 0.000,001 or $10^{-6}$; symbol $\mu$.

**MICROPHONE** - An electroacoustic transducer that responds to sound waves and delivers essentially equivalent electric waves.

**MICROPHONICS** - Production of noise as a result of magnetic shock or vibration in a system or component.

**MICROWAVE** - Term loosely applied to radio waves in the frequency range 1000 megahertz and upwards. It generally defines operations in the region where distributed-constant circuits enclosed by conducting boundaries are used instead of conventional lumped-constant circuit components.

**MICROWAVE AMPLIFICATION BY STIMULATED EMISSION OF RADIATION** - (MASER) A low-noise radio-frequency amplifier. Emission of energy stored in a molecular or atomic system by a microwave power supply is stimulated by the input signal.

**MICROWAVE OSCILLATOR** - An RF oscillator used to generate waves in the microwave regions. Circuit elements are usually of the distributed-constant type, such as cavity resonators. Because of transmit time in the frequency of interest, ordinary lumped-constant elements cannot be used.

**MILLER EFFECT** - Increase in the effective grid-cathode capacitance of a vacuum tube due to the charge induced electrostatically on the grid by the plate through the grid-plate capacitance.

**MILLI** - Prefix adopted by the National Bureau of Standards meaning 0.001 or $10^{-3}$.

**MINORITY CARRIER** - In semiconductors, the type of carrier constituting less than half of the total number of carriers.

**MIXER** - (1) Device ordinarily consisting of one or more potentiometers for combining the audio-frequency output signals of two or more microphones, or other audio-frequency signal sources in any desired proportion at the input of a main audio-frequency amplifier. (2) Stage in a heterodyne receiver in which the incoming signal is modulated with the signal from the local oscillator to produce the intermediate frequency signal. (3) Detector in a superheterodyne receiver in which there is introduced a heterodyne frequency.

**MODE** - (1) One of several types of electromagnetic wave oscillation that may be sustained in a given resonant system. Each type of vibration is designed as a particular mode, and has its own particular electric and magnetic field configurations. (2) One of several methods of exciting a resonant system. The term has also been used to describe the existence of a number of different input voltages which allow operation of a klystron at the same frequency.

**MODE OF VIBRATION** - Mode of vibration of a vibratory body such as a piezoelectric crystal unit, is a pattern of motion of the individual particles due to stresses applied to the body, its properties, and the boundary conditions. Three common modes of vibration are flexural, extensional, and shear.

**MODULATION** - The process in which the amplitude, frequency, or phase of a carrier wave is varied with time in accordance with the wave form of superimposed intelligence.

**MODULATION ENVELOPE** - Curve drawn through the peaks of a graph showing the waveform of a modulated carrier representing the waveform of the intelligence carried by the signal. The modulation envelope is the intelligence waveform.

**MODULATION FACTOR** - The ratio of the peak variation actually used to the maximum design variation in a given type of modulation. NOTE: In conventional amplitude modulation the maximum design variation is considered that for which the instantaneous amplitude of the modulated wave reaches zero.

**MOLECULAR THEORY OF MAGNETISM** - Assumption that each molecule of matter is a separate magnet and that in ferromagnetic materials these molecules all line up with their magnetic poles pointing in the same direction when the material is magnetized.

**MONOSTABLE** - Term used to describe a circuit with one stable state and one quasi-stable state. The circuit requires an external trigger to perform one cycle.

**MOTORBOATING** - Oscillation in a system or component, usually manifested by a succession of pulses occurring at a low-audio frequency.

**MOVING TARGET INDICATOR** - A device which limits the display of radar information primarily to moving targets.

**MU** ($\mu$) - Permeability, amplification factor, prefix micro.

**MU FACTOR** - Ratio of the change in one electrode voltage to the change in another electrode voltage under the conditions that a specified current remains unchanged and that all other electrode voltages are maintained constant. It is a measure of the relative effect of the voltages on two electrodes upon the current in the circuit of any specified electrode.

**MULTIMETER** - Single test instrument having a number of different ranges for measuring voltage, current, and resistance. Also called VOLT-OHM-MILLIMETER.

**MULTIELECTRODE TUBE** - An electron tube containing more than three electrodes associated with a single electron stream.

**MULTIPLEX** - Equipment or technique of combining multiple independent channels, voice or teletype, into a complex signal which in turn is transmitted to a companion terminal and restored to individual channels.

**MULTIPLIER** - (1) Resistance used in series with a voltmeter to permit measurements of higher voltages than are indicated on the meter scale. (2) Device which has two or more inputs and whose output is a representation of the product of the signed magnitudes represented by input signals.

**MULTIUNIT TUBE** - Electron tube containing within one glass or metal envelope two or more groups of electrodes, each associated with separate electron streams.

**MULTIVIBRATOR** - Form of relaxation oscillator which comprises two stages, so coupled that the input of each one is derived from the output of the other. A multivibrator is termed "free-running" or "driven," according to whether its frequency is determined by its own circuit constants or by an external synchronizing voltage.

**MUTING CIRCUIT** - (1) Circuit which cuts off the output of a receiver when no RF carrier greater than a predetermined intensity is reaching the first detector. (2) Circuit for making a receiver insensitive during operation of its associated transmitter.

**MUTUAL CONDUCTANCE** - The change in plate current of a vacuum tube divided by the change in grid voltage that causes the change in plate current, other tube element parameters remaining constant. It is a figure of merit of the tube's effectiveness as an amplifier. It is measured in mhos and is also called transconductance.

**MUTUAL INDUCTANCE** - Common property of two associated electric circuits which determines, for a given rate of change of current in one of the circuits, the electromotive force induced in the other.

**NAND-GATE** - Circuit which inverts the normal output of an AND-circuit; a Not-AND-circuit.

**NANO** - A prefix used with a basic unit of measure to indicate that the unit is $10^{-9}$.

**NEGATIVE** - (1) Terminal or electrode having more electrons than normal. Electrons flow out of the negative terminal of a voltage source. (Designation used to describe an opposite character to positive, as in negative resistance, negative transmission, negative feedback, etc.

**NEGATIVE FEEDBACK** - (1) Electron-tube circuit in which a signal fed back from the plate to the grid circuit is 180° out of phase with the input signal, resulting in a decrease in amplification, but a reduction in distortion. (2) Feedback from a high-level point to a low-level point of an amplifier so phased as to reduce the net gain of the amplifier.

**NEGATIVE RESISTANCE** - Term applied to the characteristic of a circuit or device in which current increases when the voltage is decreased.

**NEGATIVE TEMPERATURE COEFFICIENT** - Temperature coefficient expressing the amount of reduction in the value of a quantity, such as resistance for each degree of increase in temperature.

**NEUTRAL** - In a normal condition, hence neither positive nor negative. A neutral object has a normal number of electrons.

**NEUTRALIZE** - (1) To counteract any force to attain a neutral condition. (2) Process of nullifying the voltage fed back through the interelectrode capacitance of an amplifier, by providing an equal voltage of opposite phase.

**NEUTRALIZING CIRCUIT** - Portion of an amplifier circuit which provides an intentional feedback to cancel the effects of reactive feedback.

**NODES** - Points, line, or surfaces of a stationary wave system which have a zero amplitude. NOTE: There are different types of nodes, such as pressure nodes or velocity nodes, and hence, the type must be specified.

**NOISE** - (1) Undesired sound. By extension, any unwanted disturbance within a useful frequency band such as undesired electric waves in any transmission channel or device. (2) Unintelligible signals in a communication system which tend to interfere with proper perception of the desired signals or speech. (3) Unwanted energy (or the voltage produced), usually of random character, present in a transmission system due to any causes.

**NOISE LIMITER** - A circuit that cuts off all noise peaks that are stronger than the highest peak in the desired signal that is being received, thereby preventing loud, crashing noises due to strong atmospheric or manmade interference.

**NONLINEAR** - A response which is other than directly or inversely proportional to a given variable.

**NONRESONANT LINE** - Transmission line having no reflected waves and neither current nor voltage standing waves.

**NOR-GATE** - Circuit which inverts the normal output of an OR-gate; Not-OR-gate.

**NPN SEMICONDUCTOR** - A double junction formed by sandwiching a thin slice of P-type material between two layers of N-type material of a semiconductor.

**NPN TRANSISTOR** - A transistor which consists of a thin slice of P-type semiconductor material sandwiched between two layers of N-type semiconductor material.

**NPIN TRANSISTOR** - An NPN transistor which has had a layer of high purity germanium placed between the base and collector to extend the frequency range.

N-TYPE SEMICONDUCTOR - An extrinsic semiconductor in which the conduction electron density exceeds the hole density. NOTE: It is implied that the net ionized impurity concentration is donor type.

NUCLEUS - Central part of the atom which makes up most of the weight of the atom. An atomic nucleus is made up of two kinds of fundamental particles, protons, and neutrons. It has a positive charge equal to the number of protons it contains.

NULL - Minimum or zero value of current in an electrical circuit.

OCTAL BASE - Tube base having a central aligning key and positioned for eight equally spaced pins. Pins not needed for a particular tube are omitted without changing the position of the remaining pins.

OERSTED - Unit of magnetic field strength (magnetic intensity, magnetizing force) H in centimeter-gram-second electromagnetic system. At any point in a vacuum, the value of the magnetic intensity in oersteds is equal to the force in dynes exerted on a unit magnetic pole placed at that point.

OHM - The unit of electrical resistance. It is that value of electrical resistance through which a constant potential difference of 1 volt across the resistance will maintain a current flow of 1 ampere through the resistance.

OHMIC VALUE - Resistance in ohms.

OHMMETER - Instrument for measuring electric resistance.

OHMMETER ZERO ADJUSTMENT - Potentiometer or other means provided to compensate for the reduction of battery voltage with age in an ohmmeter.

OHM'S LAW - The current in an electric circuit is directly proportional to the electromotive force in the circuit. It is the fundamental law of electrical circuits and is true of all metallic circuits and most circuits containing an electrolyte resistance. The most common form of the law is $E = IR$, where E is the electromotive force or voltage across the circuit, I is the current flowing in the circuit, and R is the resistance of the circuit.

OHMS PER VOLT - Sensitivity rating for measuring instruments, obtained by dividing the resistance of the instrument in ohms at a particular range by the full-scale voltage value at that range. The higher the ohms-per-volt rating, the greater the sensitivity.

OPEN CIRCUIT - (1) Condition of an electrical circuit caused by the breaking of continuity of one or more conductors of the circuit; usually an undesired condition. (2) Arrangement of conductors and equipment that depends upon lack of continuity for operation; as open-circuit telegraphy. (3) Circuit which does not provide a complete path for the flow of current.

OPERATING POINT - The point on a family of characteristic curves of a vacuum tube or transistor where the coordinates of the point represent the instantaneous values of the electrode voltages and currents for the operating conditions under study or consideration.

OPTIMUM COUPLING - Degree of coupling that provides maximum transfer of signal energy at a given resonant frequency from one radio-frequency circuit to another.

OR-CIRCUIT - In computers, a circuit or device whose output is energized when one or more of the inputs is in its prescribed state. Also called OR-gate. An OR-circuit performs the function of the logical "OR."

ORIENT - Rotate or otherwise adjust with respect to some reference.

**OSCILLATOR** - (1) Electronic device which generates alternating-current power at a frequency determined by the values of certain constants in its circuits. An oscillator may be considered an amplifier with positive feedback with circuit parameters that restrict the oscillations of the device to a single frequency. (2) Nonrotating device which is capable of setting up and maintaining oscillations at a frequency determined by the physical constants of the system, such as a vacuum-tube, spark, or arc generator. (3) Circuit generally using a transistor capable of converting direct current into alternating current of a frequency determined by the inductive and capacitive constants of the circuit. (4) Device used to generate and repetitiously oscillate at radio frequencies.

**OSCILLATORY CIRCUIT** - Circuit containing inductance and/or capacitance, and resistance, so connected that a voltage impulse will produce an output current which periodically reverses polarity.

**OSCILLOSCOPE** - Instrument which makes possible the visual inspection of the waveform of rapidly varying quantities. It consists, in general, of three parts; an amplifier, time-base generating circuits, and a cathode-ray tube for translation of electrical energy into light energy.

**OUT-OF-PHASE** - Having waveforms that are of the same shape but do not pass through corresponding values at the same instants.

**OUTPUT** - (1) Current, voltage, power, or driving force delivered by a circuit or device. (2) Terminals or other places where current, voltage, power or driving force may be delivered by a circuit or device. (3) In computers, information transferred from internal storage to external storage.

**OUTPUT IMPEDANCE** - Impedance presented by a device to the load.

**OUTPUT METER** - Alternating-current voltmeter connected to the output of a receiver or amplifier in order to measure output signal strength.

**OVERDRIVEN AMPLIFIER** - Amplifier stage which is designed to distort the input signal waveform by permitting the signal to drive the stage beyond cutoff and/or saturation.

**OVERLOAD** - (1) In electronics, that quantity of power from an amplifier or other component or from a whole transmission system which is sufficient to produce unwanted waveform distortion. (2) Load greater than the rated load of an electric device.

**OVERTONE** - One of the frequencies, in addition to the lowest frequency, with which a vibrating body or system can freely oscillate.

**OVERTONE TYPE PIEZOELECTRIC CRYSTAL UNIT** - Crystal unit designed to utilize an overtone of the fundamental frequency of resonance for a particular mode of vibration.

**OXIDE** - Element combined with oxygen. Rust is an oxide of iron.

**PADDER CAPACITOR** - Adjustable capacitor used in conjunction with a main tuning capacitor when ganged tuning of several stages is employed. Its purpose is to permit adjustments for proper tracking of a local oscillator.

**PARALLEL CIRCUIT** - Two or more electrical devices connected to the same pair of terminals so separate currents flow through each; electrons have more than one path to travel from the negative to the positive terminal.

**PARALLEL-RESONANT CIRCUIT** - (1) Resonant circuit in which the applied voltage is connected across a parallel circuit formed by a capacitor and an inductor. (2) Inductor and capacitor connected in parallel to furnish a high impedance at the frequency to which the circuit is resonant.

**PARAMAGNETIC** - Having a magnetic permeability greater than that of a vacuum and essentially independent of the magnetizing force. In ferromagnetic materials, the permeability varies with the magnetizing force.

**PARAMETER** - (1) One of the constants entering into a functional equation, and corresponding to some characteristic property, dimension, or degree of freedom. (2) One of the resistance, inductance, mutual inductance, or capacitance values involved in a circuit or network.

**PARAMETRIC AMPLIFIER** - A solid state amplifier used for amplification of radio frequencies. A parametric amplifier uses especially constructed semiconductor diodes with a source of power supplied by a high-frequency oscillator, rather than the normal DC power source. The power source is called a "pump" and must be extremely stable. The pump is fixed in frequency and must operate at a frequency at least twice as high as the one to be amplified. Liquid nitrogen is used as a coolant to reduce thermal noise, and the spatial motion of the electrons through the semiconductor further reduces noise.

**PARAPHASE AMPLIFIER** - Amplifier which converts a single input into two outputs, which are equal in magnitude and opposite in polarity (or phase).

**PARASITE** - Current in a circuit, due to some unintentional cause, such as inequalities of temperature or of composition; particularly troublesome in electrical measurements.

**PARASITIC OSCILLATION** - (1) Undesired, self-sustaining oscillations at a frequency different from the operating frequency, occurring chiefly in vacuum-tube circuits. (2) Any unwanted oscillation in an oscillator or amplifier stage.

**PARASITIC SUPPRESSOR** - A device connected in a circuit for the purpose of suppression of parasitic oscillations.

**PART** - In electronics, a mechanical unit which cannot readily be subdivided such as a tube, a resistor, an RF coil, etc. Assembled parts make up a component.

**PATCH CORD** - Cord, terminated on each end with a plug, which is used in patching between circuit terminated in jacks.

**PEAK** - Maximum instantaneous value of an alternating quantity.

**PEAK ENVELOPE POWER OF A RADIO TRANSMITTER** - The average power supplied to the antenna transmission line by a transmitter during one radio frequency cycle at the highest crest of the modulation envelope, taken under conditions of normal operation.

**PEAKING NETWORK** - Type of interstage coupling network in which an inductance is effectively in series (series-peaking network), or in shunt (shunt-peaking network) with the parasitic capacitance to increase the amplification at the upper end of the frequency range.

**PEAK INVERSE VOLTAGE** - The maximum instantaneous anode-to-cathode voltage in the reverse direction which is actually applied to the diode in an operating circuit. NOTE: This is an application term not to be confused with breakdown voltage which is a property of the device.

**PEAK POWER OUTPUT** - (1) In a modulated carrier system, the output power, averaged over a carrier cycle, at the maximum amplitude which can occur with any combination of signals to be transmitted. (2) Maximum value of the transmitted pulse in a pulse radar system.

**PEAK-TO-PEAK AMPLITUDE** - Amplitude of an alternating quantity measured from positive peak to negative peak.

**PELTIER EFFECT** - When a current flows across the junction of two dissimilar metals, it causes either an absorption or liberation of heat, depending on the direction of the current, at a rate proportional to the first power of the current.

**PENTAGRID** - Pentagrid tube used as a converter in a superheterodyne receiver.

**PENTAGRID TUBE** - Tube having five grids.

**PENTODE** - Five-electrode vacuum tube containing an anode, a cathode, a control grid, and two additional electrodes ordinarily in the the nature of grids.

**PENTODE TRANSISTOR** - A point-contact transistor with four-point-contact electrodes. The body serves as a base with three emitters and one collector.

**PERCENTAGE MODULATION** - (1) In amplitude modulation, the ratio of half the difference between the maximum and minimum amplitudes of an amplitude, expressed in percent. (2) In frequency modulation, the ratio of the actual frequency swing to the frequency swing required for 100 percent modulation, expressed in percentage. (3) The modulation factor multiplied by 100 to express it as a percentage. (4) In FCC regulations, the term "percentage modulation" as applied to frequency modulation means the ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For FM broadcast stations a frequency swing of ±75 kc is defined as 100 percent modulation.

**PERMANENT MAGNET** - Piece of hardened steel or other magnetic material that has been strongly magnetized and retains its magnetism indefinitely.

**PERMEABILITY** - Measure of the ability of a material to act as a path for magnetic lines of force.

**PERMEABILITY TUNING** - Process of tuning a resonant circuit by varying the permeability of an inductor. It is usually accomplished by varying the amount of magnetic core material of the inductor by slug movement.

**PERSISTENCE** - Measure of the length of time during which phosphorescent light is emitted from the screen of a cathode-ray tube.

**PHANTASTRON** - An electronic circuit of the multivibrator type which is normally used in the monostable form. It is a stable trigger generator in this connection, and is used in radar systems for gating functions and sweep delay functions.

**PHASE** - (1) Position of a wave relative to the beginning of any electrical or mechanical wave. Usually expressed in degrees of an angle, the complete cycle being 360°. (2) Phase of a periodic quantity, for a particular value of the independent variable, is the fractional part of a period through which the independent variable has advanced, measured from an arbitrary origin. In the case of a simple sinusoidal quantity, the origin is usually taken as the last previous passage through zero from the negative to positive direction. The origin is generally so chosen that the fraction is less than unity.

**PHASE ANGLE, CURRENT TRANSFORMER** - Of a current transformer angle between the primary current vector and the secondary current vector reversed. This angle is conveniently considered as positive when the reversed secondary current vector leads the primary current vector.

**PHASE ANGLE, POTENTIAL TRANSFORMER** - Of a voltage transformer, angle between the primary voltage vector and the secondary voltage vector reversed. This angle is conveniently considered as positive when the reversed secondary voltage vector leads the primary voltage vector.

**PHASE DIFFERENCE** - Time in electrical degrees by which one wave leads or lags another.

**PHASE DISTORTION** - (1) Lack of direct proportionality of phase shift to frequency over the frequency range required for transmission; or the effect of such departure on a transmitted signal. (2) Impairmen of fidelity due to nonlinear phase characteristics which cause various frequencies of an applied waveform to be delayed disproportionately.

PHASE INVERSION - Phase difference of 180° between two sine waves of the same frequency.

PHASE INVERTER - A stage in an amplifier or other circuit whose chief function is to change the phase of a sine wave signal by 180°.

PHASE SHIFT - Change in the phase of a sinusoidal wave. Expressed in degrees either leading or lagging.

PHASE-SHIFT OSCILLATOR - Oscillator produced by connecting, between the output and the input of an amplifier, a network having a phase shift of an odd multiple of 180° per amplifier stage at the frequency of oscillation.

PHASE SPLITTER - (1) Device which produces, from a single input wave, two or more output waves which differ in polarity (phase) from one another. (2) In color television, the stage which takes I and Q signals from demodulators and produces four signals, positive and negative I and Q.

PHOTOELECTRIC CELL - General term applying to any cell whose electrical properties are affected by illumination, such as photovoltaic or photoconductive cells.

PHOTOSENSITIVE - Capable of emitting electrons when illuminated by light rays.

PICO - A prefix adopted by the National Bureau of Standards meaning $10^{-12}$.

PIEZOELECTRIC EFFECT - (1) That property of certain natural and synthetic crystals by which they are mechanically deformed under the influence of an electric field. (2) Effect of producing a voltage by placing a stress, either by compression, expansion, or twisting, on a crystal and, conversely, producing a stress in a crystal by applying a voltage to it.

PI NETWORK - Network of three impedances, two across the line and the third inserted in one line between the first two. Connected in a manner resembling the Greek letter $\pi$.

PLATE - (1) Principal anode in an electron tube. (2) One of the conductive electrodes in a capacitor. (3) One of the electrodes in a storage battery.

PLATE CHARACTERISTIC - Graph plotted to show how the plate current of a vacuum tube is affected by changes in plate voltage.

PLATE CIRCUIT - Complete external electrical circuit connected between the plate and the cathode of an electron tube.

PLATE CURRENT - Electron flow from the cathode to the plate inside a vacuum tube.

PLATE MODULATION - Modulation produced by application of modulating voltage to the plate of any tube in which the carrier is present.

PLATE SATURATION - Condition in which the plate current of a vacuum tube cannot be further increased by increasing the plate voltage.

PLATE VOLTAGE - Direct-current voltage that exists between the plate and cathode of a vacuum tube.

PNIP TRANSISTOR - A PNP transistor which will operate in high-frequency ranges. A layer of high purity germanium is placed between the base and collector to extend the frequency range.

PNP TRANSISTOR - A junction transistor formed by a slice of N-type semiconductor between two layers of P-type semiconductor. Amplification is by means of hole conduction.

POLARITY - (1) Condition in an electrical circuit by which the direction of the flow of current can be determined. Usually applied to batteries and other direct voltage sources. (2) Two opposite charges, one positive and one negative. (3) Quality of having two opposite magnetic poles, one north and the other south.

**POLARIZED PLUG** - Plug which is so constructed that it can be inserted into a jack or receptacle in only one position.

**POLE PIECE** - Piece of ferromagnetic material forming one end of a magnet and shaped so as to control the distribution of the magnetic flux in the adjacent medium.

**POSITIVE** - Terminal or electrode having a deficiency of electrons or point to which electrons are attracted.

**POSITIVE CHARGE** - Condition existing in a body having fewer electrons than normal.

**POSITIVE FEEDBACK** - Process by which a part of the power in the output circuit of an amplifying device reacts upon the input circuit in such a manner as to reinforce the initial power, thereby increasing the amplification.

**POSITIVE TEMPERATURE COEFFICIENT** - Characteristic of a device or substance in which the resistance of a substance increases when temperature increases.

**POTENTIAL** - Difference in voltage between two points of a circuit; frequently one is assumed to be ground (zero potential). Generally expressed in volts.

**POTENTIAL BARRIER** - Region in which the electrical potential is such that moving electric charges attempting to pass through it encounter opposition and may be turned back.

**POTENTIAL DIFFERENCE** - (1) Algebraic difference between the individual potentials of two points. (2) Voltage existing between two points.

**POTENTIAL ENERGY** - Of a body or of a system of bodies in a given configuration, the work required to bring the system from an arbitrarily chosen reference configuration to the given configuration without change in the kinetic energy of the system.

**POTENTIOMETER** - (1) An instrument for measuring an unknown electromotive force or potential difference by balancing it, wholly or in part, by a known potential difference produced by the flow of known currents in a network of circuits of known electrical constants. (2) A 3-terminal rheostat, or a resistor with one or more sliding contacts, which functions as an adjustable voltage divider.

**POWDERED IRON CORE** - Core consisting of fine particles of magnetic material, mixed, insulated from each other, and pressed into shape.

**POWER** - (1) Time rate of doing work or expending energy. In electrical systems, the basic unit is the watt. (2) Lens power is a measure of ability to bend or refract light. (3) In a DC circuit, the power in watts equals volts multiplied by amperes.

**POWER AMPLIFICATION** - Process of amplifying a signal to produce a gain in power as distinguished from voltage amplification. The gain is the ratio of the alternating power output to the alternating power input of an amplifier.

**POWER FACTOR** - Ratio of the true power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings; the ratio of resistance to impedance, and therefore, a measure of the loss in an inductor, capacitor, or insulator; and the cosine of the phase angle between a sinusoidal voltage to a load and the current passing through it. (Sometimes the cosine is multiplied by 100 and expressed as a percentage.)

**POWER GAIN** - Ratio of output power of a stage to input power. The gain is usually expressed in decibels. The operating conditions are specified and if either the input or output has more than one component, then the components and the weights assigned should be specified.

**POWER SUPPLY** - (1) Source of electrical energy required for communication operations. (2) Source of current used to heat the filament of an electron tube. (3) Power supply that furnishes DC voltages required by the electrodes of vacuum tubes. (4) Power supply that furnishes the steady voltage required by the electrodes of transistors.

**POWER TRANSFORMER** - Transformer used to change a supply voltage to the various higher and lower values required.

**PRESELECTOR** - Device, placed ahead of a frequency converter or other device, which passes signals of desired frequencies and reduces others.

**PRESSURIZATION** - Process of surrounding the critical parts of equipment designed for high-altitude operation with desiccated air or an inert gas under elevated pressure (about 5 pounds per square inch at sea level), for the purpose of avoiding breakdowns which might result from the impairment of the insulating properties of air at reduced pressure.

**PRIMARY** - (1) Transformer winding which receives energy from a supply circuit. (2) High voltage conductors of a power distribution system.

**PRIMARY CURRENT** - Current flowing through the primary winding of a transformer.

**PRIMARY EMISSION** - Emission of electrons due to primary causes, such as heating of a cathode, and not to secondary effects, such as electron bombardment.

**PRIMARY VOLTAGE** - Voltage applied to the terminals of the primary winding of a transformer.

**PRINTED CIRCUIT** - A circuit formed by depositing conducting material on the surface of an insulated sheet. Circuit components such as wiring, resistance, capacitances, inductors, etc., are etched on the sheet by various processes.

**PROPAGATION** - (1) In electrical practice, the travel of waves through or along a medium. (2) Traveling of a wave along a transmission path. (3) Travel of electromagnetic waves or sound waves through a medium. Propagation does not refer to the flow of current in the ordinary sense.

**PROTON** - Positive particle in an atom. The smallest quantity of positive electricity that can exist in a free state.

**P-TYPE SEMICONDUCTOR** - An extrinsic semiconductor in which the mobile hole concentration exceeds the conduction electron concentration. It is implied that the net ionized impurity concentration is acceptor type.

**P+ TYPE SEMICONDUCTOR** - A P-type semiconductor in which the excess mobile hole concentration is very large.

**PULLING FREQUENCY** - Tendency of any load to change the frequency of an oscillator.

**PULSATING CURRENT** - Nonuniform or varying electron flow, the variations of which take place at regular periods of time and may or may not include reversals of the direction of electron flow. There is usually an electron drift in one direction.

**PULSATING VOLTAGE** - Varying voltage, the variations of which take place during regular periods of time and may or may not include reversal of polarity. When applied to a conductor, a pulsating voltage causes an electron flow such that the average electron displacement is not zero, and there is an average electron drift in one direction.

**PULSE** - (1) A brief excursion of a quantity from normal. (2) Signal characterized by the rise and decay in time of a quantity, the value of which is normally constant. (3) In radio, surge of electrical energy of short duration. (4) Voltage level of short duration used in computers to represent a bit. (5) Single disturbance characterized by the rise and decay in time or space of a quantity whose value is normally constant. (6) Single impulse of a telephone dial or similar signal. (7) In relay operation, sudden change of brief duration produced in the current or voltage of a circuit to actuate or control a switch or relay. NOTE: In these definitions, an RF carrier, amplitude-modulated by a pulse, is not considered to be a pulse.

**PULSE AMPLITUDE** - Maximum instantaneous value of a pulse. NOTE: Spikes and ripples superimposed on the pulse are commonly considered to be separate transients and are ignored in considering dimensions of the pulse itself.

**PULSE DURATION** - Time interval between the first and last instants at which the instantaneous amplitude reaches a stated fraction of the peak pulse amplitude.

**PULSE-DURATION MODULATION** - Pulse-time modulation in which the value of each instantaneous sample of the modulating wave is caused to modulate the duration of the pulse. NOTE: (1) Pulse-length modulation has been used to design this system of modulation. (2) In pulse-duration modulation, the modulating wave may vary the time of occurrence of the leading edge, the trailing edge, or both edges of the pulse.

**PULSE-FORMING NETWORK OR CIRCUIT** - Network or circuit whch serves to produce a pulse of the required waveform.

**PULSE FREQUENCY MODULATION** - Form of pulse-time modulation in which the pulse repetition frequency of the carrier is varied in accordance with amplitude and frequency of the modulating signal.

**PULSE MODULATION** - (1) Modulation of a carrier by pulses. (2) Modulation of a pulse carrier.

**PULSE REPETITION FREQUENCY** - The frequency at which pulses are transmitted by a pulse-modulated transmission system, such as a radar set. It is usually given in pulses per second. It is also called pulse rate and pulse recurrence rate. It is the reciprocal of the pulse recurrence period.

**PULSE REPETITION RATE** - See PULSE REPETITION FREQUENCY.

**PUMP OSCILLATOR** - An AC generator that supplies pumping energy for maser and parametric amplifiers. Operates at twice or some higher multiple of the signal frequency.

**PUSH-PULL CIRCUIT** - Circuit containing two like elements which operate in 180° phase relationship to produce additive output components of the desired wave, with cancellation of certain unwanted products.

**Q** - Figure of merit of efficiency of a circuit or coil. Ratio of inductive reactance to resistance in servos. Relationship between stored energy and rate of dissipation in certain types of electric elements, structures, or materials.

**QUARTER-WAVE ANTENNA** - Antenna which has an electrical length equal to one-fourth the wavelength of the signal to be transmitted or received. Its physical length will be slightly shorter than one-fourth wavelength.

**QUARTZ CRYSTAL** - (1) Mother crystal of quartz as found in nature, having a hexagonal cross section coming to a point at one end and a fractured base where it was broken away from the rock formation in which it grew. (2) Crystal unit in the form of a thin slab or plate cut from the quartz crystal and carefully ground to a thickness that will make it vibrate at a specific frequency when supplied with energy. It is used, among other purposes, to control the frequency of an oscillator in a transmitter.

**QUIESCENT STATE** - Time during which a tube or other element of an electric circuit is not performing its active function in the circuit.

**RADAR** - See RADIO DETECTION AND RANGING.

**RADIATION** - (1) Emission of energy in the form of electromagnetic waves. The term is also used to describe the radiated energy. (2) Corpuscular emissions, as alpha and beta radiation and emissions of mixed or unknown type, such as cosmic radiation.

**RADIATION FIELD** - Electromagnetic energy that breaks away from a transmitting antenna and radiates outward into space as electromagnetic waves (radio waves).

**RADIO** - (1) The use of electromagnetic waves to transmit or receive electric impulses or signals without a connecting wire; the transmission or reception of such impulses or signals. (2) Specifically, the use of these waves to transmit electric pulses excited by the voice or other sounds, or by nonauditory instruments at frequencies below those normally used in radar or television. (3) Any aggregate of electric and electronic equipment used for the wireless transmission or reception of electromagnetic waves, or both, especially for transmitting and receiving sounds, activating remote-control mechanisms, etc.; a radio set. (4) A manner or technique of doing something by means of, or with the aid of, radio (in sense 2), as communicating, navigating aircraft, controlling, etc., as in the phrase "the missile was guided by radio."

**RADIO DETECTION AND RANGING** - (radar) (1) Any of certain methods or systems of using beamed and reflected electromagnetic energy for detecting and locating objects; for measuring distance, velocity, or altitude; or for certain other purposes such as navigating, homing, bombing, missile tracking, mapping, etc. (2) In FCC regulations, a radio determination system based on the comparison of reference signals with radio signals reflected, or retransmitted, from the position to be determined.

**RADIO FIX** - (1) The location of a friendly or enemy radio transmitter, determined by finding the direction of the radio transmitter from two or more listening stations. (2) The determination of a navigational position by a ship or aircraft by ascertaining the direction of radio signals received from two or more sending stations, the locations of which are unknown.

**RADIO FREQUENCY** - Frequency in which radio transmission is useful for communication purposes. The useful range is from approximately 10 kilohertz to 300,000 megahertz.

**RADIO WAVE** - Electromagnetic waves of frequencies lower than 3,000 gigahertz, propagated in space without artificial guide.

**RATE** - Measure of movement per unit of time; e.g., climb, closure, descent, or turn.

**RATED OUTPUT** - Output power, voltage, current, etc., at which a machine, device, or apparatus is designed to operate under specified normal conditions.

**RATE GROWN SEMICONDUCTOR** - A grown junction produced by varying the rate of crystal growth.

**RATIO DETECTOR** - Type of detector used to convert FM signals to amplitude changes.

**RC CONSTANT** - Time constant of a resistor-capacitor circuit; equal in seconds to the resistance value in ohms multiplied by the capacitance value in farads.

**RC (RESISTIVE-CAPACITIVE) COUPLING** - Coupling between two or more circuits, usually amplifier stages, by means of a combination of resistive and capacitive elements.

**RC NETWORK** - Circuit containing resistances and capacitances arranged in a particular manner to perform a specific function.

**RC OSCILLATOR** - Oscillator in which the frequency is determined by resistance and capacitance elements.

**REACTANCE** - In electrical circuits, reactance is the imaginary component of impedance. The symbol for reactance is X.

**REACTANCE MODULATOR** - Device, the reactance of which may be varied in accordance with the instantaneous amplitude of the modulating wave applied. Electron tubes are widely used in this manner to effect phase or frequency modulation.

**REACTANCE TUBE** - A vacuum tube operated in such a manner that it presents almost a pure reactance to the circuit.

**REACTANCE LOAD** - Load having reactance, such as a capacitive load or an inductive load, rather than a resistive load.

**RECEIVING ANTENNA** - Device for converting received space propagated electromagnetic energy to electrical energy.

**RECEIVING CIRCUIT** - Apparatus and connections used exclusively for the reception of messages at a radio telephone or radio telegraph station.

**RECTIFICATION** - Conversion of alternating current into unidirectional current by means of a rectifier.

**RECTIFIER** - (1) A device having an asymmetrical conduction characteristic, employed in such a manner as to convert alternating current into unidirectional current. In amplitude modulation detection, recovery of original signals is frequently accomplished by a rectifier. (2) Device that converts alternating current into unidirectional current by permitting appreciable current flow in one direction only.

**REFERENCE LEVEL** - Level used as a starting point when designating the value of an alternating quantity or a change in the quantity by means of decibel units. For sound loudness, the reference level is usually the threshold of hearing. For communication receivers, the commonly used level is 60 microwatts. A common reference in electronics is 1 milliwatt and power is stated as decibels above or below 1 milliwatt (dbm).

**REFERENCE VOLTAGE** - The AC voltage in a synchro servosystem used to determine the in-phase or 180°-out-of-phase condition in order to provide directional sense.

**REFLECTED IMPEDANCE** - (1) Impedance value that appears to exist across the primary of a transformer due to current flowing in the secondary. (2) Impedance which appears at the input terminals as a result of the characteristics of the impedance at the output terminals.

**REFLECTED WAVE** - (1) Part of the incident wave reflected back into the first medium. (2) Sky wave reflected from the ionosphere layer back to earth. (3) Wave reflected from the junction of two media with different reflective indices.

**REFLECTOR** - (1) Device to redirect radiation in a desired direction or directions. (2) Rear portion (parasitic element) of a directional antenna, not connected to the transmitter or receiver, and so designed as to increase the radiation effectiveness in the forward direction. (3) Element in a reflex klystron tube which reflects the electrons back toward the grid.

**REFLEX KLYSTRON** - Klystron which employs a reflector (repeller) electrode, in place of a second resonant cavity, to redirect the velocity-modulated electrons through the resonant cavity which produced the modulation. Such klystrons are well suited for use as oscillators because the frequency is easily controlled by varying the position of the reflector.

**REGENERATION** - Process by which a part of the power in the output circuit of an amplifying device reacts upon the input circuit in such a manner as to reinforce the initial power, thereby increasing the amplification. Synonym: positive feedback.

**REGENERATIVE DETECTOR** - A detector circuit in which RF energy is fed back in such a way as to produce regeneration, thereby greatly increasing the amplification and sensitivity of the circuit.

**REGULATED POWER SUPPLY** - Power supply device containing means for maintaining constant voltage or constant current under changing load conditions.

**REGULATION** - (1) Maintaining a constant level of power, voltage, signal, etc., in a circuit or system. (2) Ratio of the change in voltage due to a load to the open-circuit voltage, expressed in percent.

**RELAY** - (1) Transmission forwarded through an intermediate station. (2) Electrically operated switch, usually comprised of an electromagnet, an armature, and a number of contact springs. (3) Device in which a small current or power flow can be made to control a larger current or power flow in a secondary circuit opening or closing contacts. Usually contains an electromagnet and an armature.

RELAY CONTACTS - Contacts that are closed or opened by the movement of the armature of a relay.

RELUCTANCE - Property of a magnetic circuit which determines the amount of magnetic flux that will be produced as a result of the application of a given magnetomotive force.

REMOTE-CUTOFF TUBE - Electron tube which is designed so as to approach cutoff very gradually as the negative grid potential is increased.

REPULSION - Mechanical force tending to separate bodies having like electrical charges or like magnetic polarity, or in the case of adjacent conductors, having currents flowing in opposite directions.

RESIDUAL CHARGE - Charge remaining on the plates of a capacitor after an initial discharge of the capacitor.

RESIDUAL IONIZATION - Ionization of air or other gas in a closed chamber, not accounted for by recognizable neighboring agencies.

RESIDUAL MAGNETISM - Magnetism remaining in a substance after removal of the magnetizing force.

RESISTANCE - (1) Property of a conductor which determines the amount of current that will flow as the result of the application of a given electromotive force. All conductors possess some resistance, but when a device is made especially for the purpose of limiting current flow, it is called a resistor. A resistance of 1 ohm will allow a current of 1 ampere to flow through it when a potential of 1 volt is applied. (2) Opposition which a device or material offers to the flow of current. The effect of resistance is to raise the temperature of the material or device carrying the current. (3) Circuit element designed to offer a predetermined resistance to current flow.

RESISTANCE BRIDGE - Common form of Wheatstone bridge, employing resistance in three arms.

RESISTANCE WIRE - Wire made from a metal or alloy having high resistance per unit length, such a nichrome. Used in wire-wound resistors, heating elements, etc.

RESISTOR - Electrical component which offers resistance to the flow of current. It may be a coil of fine wire or a composition rod.

RESONANCE - Of electrical circuits, condition in a circuit containing inductance and capacitance where the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at but one frequency for a given fixed circuit and the circuit is said to be in resonance. The resonant frequency may be changed by varying either the capacity or inductance.

RESONANCE CURVE - Graphical representation illustrating the manner in which a tuned circuit responds to the various frequencies in and near the resonant frequency.

RESONANT CAVITY - Form of resonant circuit in which the current is distributed on the inner surface of an enclosed chamber. By making the chamber of the proper dimensions, the circuit can be made to have a high Q at UHF and SHF frequencies. The resonant frequency of a cavity can be changed by the adjustment of screws which protrude into the cavity, or by changing the shape of the cavity.

RESONANT FREQUENCY - (1) Frequency, of a crystal unit, for a particular mode of vibration to which, discounting dissipation, the effective impedance of the crystal unit is zero. (2) That frequency, for a given resonant circuit at which the inductive reactance is equal to the capacitive reactance.

RESONANT LINE - Transmission line having values of distributed inductance and distributed capacitance such as to make the line resonant at the frequency it is handling.

RESONATE - To bring to resonance, as by tuning.

RETENTIVITY - Ability of a material to retain its magnetism.

**REVERSE BIAS** - Bias applied to semiconductor junction with polarity, so little or no current flows through the junction.

**REVERSE CURRENT** - Of a semiconductor diode, the total current flowing through a semiconductor diode in the reverse direction.

**RF** - See RADIO FREQUENCY.

**RF AMPLIFIER** - An amplifier, stage, or section used to increase the voltage or power of radio frequency signals.

**RF CHOKE** - Coil having a high inductive reactance for radio frequencies and used to prevent radio-frequency currents from passing from one circuit to another.

**RF COMPONENT** - Portion of a signal or wave which consists of only the RF alternations, and does not include the audio rate of change.

**RF TRANSFORMER** - Transformer designed to transfer RF energy from one circuit to another.

**RHEOSTAT** - (1) Resistor whose value can be varied. (2) Variable resistor which is used for the purpose of adjusting the current in a circuit.

**RHOMBIC ANTENNA** - Directional antenna composed of long wire radiators comprising the sides of a rhombus, the two halves of the rhombus being fed equally in opposite phase at an apex. The antenna is usually terminated in an impedance.

**RING TIME** - Interval from trailing edge of transmitted pulse until signal is lost in receiver noise.

**RIPPLE** - Periodic fluctuation on a DC voltage which results from incomplete filtering in a power rectifier set, or from the bars of the commutator or a DC generating machine. The magnitude of ripple is expressed as the ratio of its effective value, to the average value of the total DC voltage, in percent.

**ROOT MEAN SQUARE** - The square root of the average of the squares of the instantaneous values of a periodic quantity taken throughout one complete period. It is the effective value of a periodic quantity.

**ROOT MEAN SQUARE VALUE** - Of alternating currents and voltages, the RMS value is the effective value of current or voltage applied. It is that alternating current or voltage that produces the same heating effect as an equal value of direct current or voltage. It is equal to 0.707 times the maximum value of a sine wave.

**ROSIN CORE SOLDER** - Solder in tubular form, the center filled with rosin, and, therefore, self-fluxing.

**ROSIN JOINT** - Connection of a conductor to a piece of equipment or another conductor supposedly securely soldered, but actually held together by rosin flux. Same as rosin connection.

**ROTARY SWITCH** - Bank and wiper switch with wipers or brushes that move only on the arc of a circle.

**ROTOR PLATES** - Rotating plates of a variable capacitor.

**SATURABLE REACTOR** - Magnetic core reactor in which a low value of current produces magnetic saturation of the core, thereby reducing the effective inductance and reactance above the saturation point.

**SATURATION** - (1) Maximum impregnation of a solid or liquid substance. (2) Maximum possible density of a magnetic field or the maximum possible vapor pressure of substance in a given space. (3) Condition in which maximum current is passing through the device. (4) Condition which exists in a circuit when an increase in the actuating component produces no further increase in the resultant effect.

**SATURATION LIMITING** - Limiting the output of an amplifier circuit by operating in the region of saturation.

**SCHEMATIC CIRCUIT DIAGRAM** - Circuit diagram in which component parts are represented by simple, easily drawn symbols. May be called schematic.

**SCREEN** - (1) Metal partition or shield which isolates a device from external magnetic or electric fields. (2) Screen-grid electrode of an electron tube. (3) Chemically coated inside surface of the large end of a cathode-ray tube which becomes luminous when struck by an electron beam.

**SECONDARY ELECTRON** - An electron emitted as a result of bombardment of a material by electrons or cathode rays, or by collision of a charged particle against a surface.

**SECONDARY EMISSION** - The ejection of electrons from a solid or liquid as a result of charged-particle impact.

**SECONDARY VOLTAGE** - Voltage across the secondary winding of a transformer.

**SECOND DETECTOR** - That portion of a superheterodyne receiver that separates the audio component from the modulated intermediate frequency.

**SELECTIVITY** - (1) That characteristic which determines the extent to which it is possible to differentiate between the desired signal and disturbances of other frequencies. (2) Ability of a receiver to reject transmissions other than the one to whch it is tuned (usually expressed by a curve in which the input signal voltage required to produce a constant power output is plotted against a frequency). (3) Degree to which a radio receiver can accept the signals of one station while rejecting those of all other stations on adjacent channels.

**SELENIUM RECTIFIER** - Rectifier formed of discs of iron in contact with a layer of metallic selenium.

**SELF-BIAS** - Condition under which a device sets its own bias.

**SELF-CONTROLLED OSCILLATOR** - Oscillator depending on its resonant circuits for frequency determination; i.e., not crystal controlled.

**SELF-INDUCTION** - (1) Action in which a counter electromotive force is produced in a conductor when the conductor's own magnetic field collapses and expands with a change in current flow. (2) Production of a voltage in a circuit by a varying current in that same circuit.

**SELSYN** - Single-phase, self-synchronous machine which converts mechanical position into electrical signal, or vice versa. Selsyn is a trade name applied to this type of synchro motor or generator.

**SEMICONDUCTOR** - A solid or liquid electronic conductor, with resistivity between that of metals and that of insulators, in which the electrical charge carrier concentration increases with increasing temperature over some temperature range. Over most of the practical temperature range, the resistance has a negative temperature coefficient. Certain semiconductors possess two types of carriers; namely, negative electrons and positive holes. The electrical properties of semiconductors are highly sensitive to the presence of impurities and to previous treatment.

**SEMICONDUCTOR DIODE** - A semiconductor device having two terminals and exhibiting a nonlinear voltage current characteristic; in more restricted usage, a semiconductor device which has the asymmetrical voltage-current characteristic exemplified by a single PN junction.

**SENSITIVITY** - (1) Sensitivity of a radio receiver or similar device is taken as the minimum input signal required to produce a specified output signal having a specified signal-to-noise ratio. This signal input may be expressed as power or as voltage, with input network impedance stipulated. (2) Least signal input capable of causing an output signal having desired characteristics.

**SERIES CIRCUIT** - Arrangement where two or more electrical devices are connected so that the current through one must flow through the other; electrons have one path to travel from the negative terminal to the positive terminal.

**SERIES EXCITATION** - Obtaining field excitation in a motor or generator by allowing the armature current to flow through the field winding.

**SERIES-PARALLEL CIRCUIT** - One in which two or more parallel or series combinations are in series with each other.

**SERIES RESONANCE** - (1) Resonance exhibited by a capacitor and inductor connected in series, characterized by low series attenuation at the resonant or tuned frequency and high series attenuation of all others. (2) Steady-state condition which exists in a circuit comprising inductance and capacitance connected in series when the current in the circuit is in phase with the voltage across the circuit. (3) Condition existing in a circuit when the source of EMF is in series with an inductance and capacitance whose reactances cancel each other at the applied frequency, reducing the impedance to minimum.

**SERIES WOUND** - Motor or generator in which the armature and field windings are in series.

**SERVOSYSTEM** - (1) Complete electromechanical system for amplifying and transmitting accurate mechanical position from one point to another by electrical means, in a closed circuit loop. The purpose of a servo is to reproduce a signal at a place, power level, or form different from the original signal, but under its control. The servosignal is usually mechanical. The circuit elements are motors, gear, or thermostats. (2) Electromechanical system which is used for positioning one element of a system in relation to another. The change in position of one element of the system results in the production of an error voltage which is used indirectly to cause a motor to drive the other element of the system to the point where the error voltage no longer exists.

**SHELL** - (1) Group of electrons which form part of the outer structure of an atom, and having a common energy level. (2) Lamina of magnetic material in which the lines of induction are in the direction of its thickness. Its strength is the magnetic moment per unit area.

**SHIELD** - (1) Housing of metal, usually aluminum or copper, placed around a radio circuit. The housing prevents interaction between circuits by providing a low resistance and reflecting path to ground for high frequency radiations. (2) Sheet or core of iron enclosing instruments or radio parts to protect them from stray magnetic fields by providing a convenient path for the magnetic lines of force.

**SHORT CIRCUIT** - Low resistance connection between two points of different potential in a circuit, usually accidental and usually resulting in excessive current flow that may cause damage.

**SHORT WAVE** - Refers to radio frequencies above the commercial broadcasting band used for sky wave communications; wavelengths less than 200 meters.

**SHOT EFFECT** - Noise voltages developed as a result of the random nature of electron travel within electron tubes. The effect is characterized by the steady hiss in audio reproduction, and by "snow" or "grass" in video reproduction.

**SHUNT** - (1) Precision, low-value resistor placed across the terminals of an ammeter to increase its range. (2) Any part connected, or the act of connecting any part, in parallel with some other part. (3) Branch of an electric circuit having its winding in parallel with the external or line circuit.

**SHUNT-WOUND** - Windings so designed in a motor or generator, that armature and field windings are in parallel.

**SIDEBANDS** - (1) Frequency bands on both sides of the carrier frequency which contain the frequencies of the waves produced by the process of modulation. (2) Wave components lying within such bands. NOTE: In the process of amplitude modulation with a sine-wave carrier, the upper sideband includes all sum (carrier plus modulating) frequencies; the lower sideband includes all difference (carrier minus modulating) frequencies.

**SIGNAL** - (1) Any transmitted electrical impulse. (2) Operationally, type of message, the text of which consists of one or more letters, words, characters, signal flags, visual displays, or special sounds, with prearranged meanings, and which is conveyed or transmitted by visual, acoustical, or electrical means. (3) A wave that conveys desired intelligence. The signal may consist of an electromagnetic wave in space, the current in or voltage impressed upon a circuit element, or the sound impinging upon the ear from a loudspeaker or headset. (4) Intelligence, message, or effect conveyed in communications and other electronic applications.

**SIGNAL GENERATOR** - Instrument which produces voltages of known amplitude and waveform for testing and measuring electronic apparatus.

**SIGNAL-TO-NOISE** - Ratio of the magnitude of the signal to that of the noise; often expressed in decibels. This ratio is expressed in many different ways; e.g., in terms of peak values in the case of impulse noise, and in terms of root-mean-square values in the case of random noise, the signal being assumed sinusoidal. In specific cases other measures of signal and noise may be used if clearly stated.

**SILICON** - Nonmetallic element which is a semiconductor and used as transistor material.

**SINE WAVE** - Wave in which the amplitude varies as the sine of the angle; the waveform of a normal alternating current or voltage.

**SINGLE-END AMPLIFIER** - Amplifier stage which normally employs only one tube or semiconductor or, if more than one tube or semiconductor is used, they are connected in parallel so that operation is asymmetric with respect to ground.

**SINGLE-PHASE CIRCUIT** - Either an alternating-current circuit which has only two points of entry, or one which, having more than two points of entry, is intended to be so energized that the potential differences between all pairs of points of entry are either in phase or differ in phase by 180°. A single-phase circuit with only two points of entry is called a single-phase, 2-wire circuit.

**SINGLE-SIDEBAND** - Term used to describe the process of single-sideband, suppressed carrier communications operations, and the equipment required for this type of operation. Within the transmitter of such a system the carrier is suppressed, either partially or completely and restored at the receiver. In single-sideband operations, only one sideband is transmitted.

**SINUSOIDAL** - Varying in proportion to the sine of an angle or time function. Ordinary alternating current is sinusoidal.

**SKIN EFFECT** - Tendency of currents at high frequencies to flow near the surface of a conductor thus being restricted to a small part of the total sectional area and producing the effect of increasing the resistance.

**SKIP DISTANCE** - (1) Minimum distance at which radio waves of a specified frequency can be transmitted at a specified time between two points on the earth by reflection from the regular ionized layers of the ionosphere. Reflected waves are received at smaller distances only by scattered or zigzag reflections. (2) Minimum distance between the transmitting station and the point of return to the earth of the transmitted wave reflected from the ionosphere.

**SKY WAVE** - Radio wave that travels upward in space from the antenna; may or may not be returned to earth by reflection from the ionosphere.

SLIP - Difference in a motor's synchronous speed and its operating speed. It may be expressed in a percent of synchronous speed, as a decimal fraction of synchronous speed, or directly in revolutions per minute (RPM).

SLIP RING - Device for making electrical connections between stationary and rotating contacts.

SLUG - (1) Heavy metal ring or short-circuited winding which is used on the core of a relay to introduce a time delay in its operation. (2) Metallic core which is moved along the axis of a coil for the purpose of tuning.

SOFT TUBE - (1) High-vacuum tube which has become defective because of the entry of a small amount of gas. (2) An electronic tube into which a small amount of gas has purposely been put in order to obtain desired characteristics. A gaseous tube.

SOLDER - Alloy of lead and tin that melts at a fairly low temperature, used in making electrical connections.

SOLDERING IRON - Tool used to apply heat to a joint preparatory to soldering.

SOLDERLESS CONNECTOR - Device for clamping two wires firmly together to provide a good connection without solder. A common form is a cap with tapered internal threads, twisted over the exposed ends of the wires.

SOLENOID - (1) Electromagnet having an energizing coil which is approximately cylindrical in form, acting on an armature positioned in the center of the coil (2) Electric conductor wound as a helix with a small pitch, or as two or more coaxial helixes. (3) Tubular coil of wire which, when traversed by an electric current, acts as a magnet and tends to pull a movable iron core to a central position.

SOURCE IMPEDANCE - Impedance presented by a source of energy to the input terminals of a device.

SPACE ATTENUATION - Loss of energy, expressed in decibels, of a signal in free air; caused by such factors as absorption, reflection, scattering, and dispersion.

SPACE CHARGE - Charge of electricity distributed throughout a volume or space. For example, negative charge due to the cloud of electrons existing in the space between the cathode and plate in a vacuum tube, formed by the electrons emitted from the cathode in excess of those immediately attracted to the plate.

SPAGHETTI - Heavily varnished cloth tubing or plastic, sometimes used to provide insulation for circuit wiring.

SPARK - Flash due to an electric discharge through air or some other dielectric material, taking place between two or more electrodes.

SPARK SUPPRESSOR - Network, usually consisting of a capacitance and resistance in series, connected across a pair of contact points to diminish sparking.

SPECTRUM ANALYZER - Test instrument used to show the distribution of energy contained in the frequencies emitted by a pulse magnetron; also used to measure the Q of resonant cavities and line; and to measure the cold impedance of a magnetron.

SPEECH AMPLIFIER - An AF voltage amplifier for amplifying signals from a microphone.

SPEECH FREQUENCY - Audio frequency in the space from about 100 to 3,000 hertz, which includes all components considered essential for intelligibility of speech.

SPLICE - Joint used for connecting in series two lengths of conductor or cable, so as to form a union with good bond and high conductivity.

SPLIT-PHASE MOTOR - Single-phase induction motor equipped with an auxiliary winding displaced in magnetic position from, and connected in parallel with the main winding.

**SPURIOUS RADIATION** - Emissions from a radio transmitter at frequencies outside of its assigned or intended emission frequency.

**SQUARE WAVE** - Periodic wave which alternately for equal lengths of time assumes one of two fixed values, the time of transition being negligible in comparison.

**SQUELCH CIRCUIT** - Circuit for preventing a radio receiver from producing audio frequency output in the absence of a signal having predetermined characteristics. A squelch circuit may be operated by signal energy in the receiver passband, by noise quieting, or by a combination of the two (ratio squelch). It may also be operated by a signal having special modulation characteristics (selective squelch).

**SQUIRREL-CAGE INDUCTION MOTOR** - Motor in which the secondary circuit consists of a squirrel-cage winding suitably placed in slots in the secondary core.

**STABILITY** - Freedom from undesired variation.

**STAGGER TUNING** - Method of aligning the IF stages of a superheterodyne receiver to produce wide bandwidth. This is accomplished by peaking alternate IF transformers at slightly different frequencies.

**STANDARD** - Exact value, or a concept that has been established by authority, custom, or agreement, to serve as a model or rule in the measurement of a quantity or in the establishment of a practice or procedure.

**STANDING WAVE** - (1) Distribution of current and voltage on a transmission line formed by two sets of waves traveling in opposite directions, and characterized by the presence of a number of points of successive maxima and minima in the distribution curves. Standing waves indicate that power is being lost in transmission; therefore, efforts are made to keep standing waves to a minimum. (2) Sinusoidal distribution of current and voltage amplitudes along a transmission line as a result of the deflection of energy from a point where a mismatch of impedance occurs.

**STANDING-WAVE RATIO** - (1) Ratio of current (or voltage) at a loop (maximum) in a transmission line to the value at a (minimum) node. It is equal to the ratio of the characteristic impedance of the line to the impedance of the load connected to the ouput end of the line. (2) Ratio of the amplitude of a standing wave at an antinode to the amplitude at a node.

**STATIC** - (1) Interference caused by natural electrical disturbances in the atmosphere, or the electromagnetic phenomena capable of causing such interference. (2) Noise heard in a radio receiver caused by electrical disturbances in the atmosphere, such as lightning, northern light, etc. (3) Fixed, nonvarying condition.

**STATOR** - (1) Portion of machine which contains the stationary parts of the magnetic circuit with their associated windings. (2) Fixed or nonmoving part of a variable capacitor.

**STEP-UP TRANSFORMER** - Transformer in which the energy transfer is from a low-voltage winding to a high-voltage winding or windings.

**STORAGE** - Ability to retain information; part of the computer which holds data.

**STRAY CAPACITANCE** - Capacitance existing between adjacent conductors or wiring. Coupling effects cause it to be detrimental at high frequencies.

**SUBATOMIC PARTICLES** - Particles that make up the atom; e.g., proton, electron, neutron, etc.

**SUBCARRIER** - (1) Carrier that is modulated and then applied as modulation on a second carrier. (2) Carrier which is applied as a modulating wave to modulate another carrier.

**SUBHARMONIC** - Sinusoidal quantity having a frequency which is an integral submultiple of the fundamental frequency of a periodic quantity to which it is related; e.g., a wave, the frequency of which is half the fundamental frequency of another wave, is called the second subharmonic of that wave.

**SUPERHETERODYNE RECEIVER** - Receiver in which the incoming modulated RF signals are amplified in a preamplifier (in some cases, but not necessarily in all receivers of this type), and then fed into a mixer (first detector) for conversion into a fixed, lower carrier (called the intermediate frequency of the receiver), the modulated IF signals undergo very high amplification in the IF amplifier stages and are then fed into a detector (second detector) for demodulation. The resulting audio or video signals are usually further amplified before use.

**SUPPRESSED CARRIER** - Term used to designate that type of system which results in the suppression of the carrier frequency from the transmission medium. The intelligence of a carrier wave after modulation is contained in either sideband, and normally only one sideband is transmitted; the other sideband and carrier frequency are suppressed. The intelligence is recovered at the receiving end by inserting a carrier frequency from a local source which when combined with the incoming signal, produces the original frequencies with which the transmitting carrier was modulated.

**SUPPRESSOR** - Resistor used to reduce or prevent oscillation or the generation of unwanted RF signals.

**SUPPRESSOR GRID** - (1) Grid which is interposed between two electrodes, both positive with respect to the cathode, to prevent the passing of secondary electrons from one to the other. Not to be confused with grid suppressor. (2) Electrode used in an electron tube to minimize the effects of unwanted secondary-electron emission from the plate or anode.

**SWEEP GENERATOR** - Circuit which applies voltage or current to the deflection elements in a cathode-ray tube in such a manner as to make the deflection for the electron beam a known function of time, against which other periodically occurring electrical phenomena may be examined, compared, or measured.

**SWINGING CHOKE** - Choke in which the effective inductance varies with the amount of current passing through it. It is used in some power supply filter circuits.

**SWITCHING** - Making, breaking, or changing the connections in electrical circuit.

**SYMBOL** - (1) In writing or printing, a conventional sign such as a character, a letter, or an abbreviation used instead of a word or words. (2) Design, letter, or abbreviation used on diagrams and maps, in formulas, etc., to represent specific characteristics, quantities, or objects. Radio parts are often represented by schematic symbols on circuit diagrams.

**SYMMETRICAL** - Balanced, therefore having equal characteristics on each side of a central line, position, or value.

**SYNCHRO** - A synchronous electric motor, used in pairs, or multiunit installations to telemeter angular motion, both in speed and total movement.

**SYNCHRONISM** - (1) Relationship between two or more periodic quantities of the same frequency when the phase difference between them is constant. (2) Applied to the synchronous motor, the condition under which the motor runs at a speed which is directly related to the frequency of the power applied to the motor and is not dependent upon other variables.

**SYNCHROSCOPE** - (1) Instrument used to determine the phase difference or degree of synchronism of two AC generators or two AC quantities. (2) Oscilloscope on which recurrent pulses or waveforms may be observed, which incorporates a sweep generator that produces on sweep for each pulse. The sweep usually is very fast to permit display of short pulses.

**TANK CIRCUIT** - (1) Tuned circuit used to store energy temporarily. (2) Parallel resonant circuit.

**TAP** - Of a transformer, a connection brought out of a winding at some point between its extremities, usually to permit changing the voltage ratio.

**TAPPED RESISTOR** - Wire-wound, fixed resistor having one or more additional terminals along its length, generally for voltage-divider applications.

**TEMPERATURE-COMPENSATING CAPACITOR** - Capacitor whose capacitance varies with temperature in a known and predictable manner, used extensively in oscillator circuits to compensate for changes in the values of other parts with temperature change.

**TERMINAL** - (1) Fitting to which electrical connections are made. (2) Final station in a radio relay system.

**TERMINAL BOARD** - Insulating base or slab, equipped with terminals for connecting wiring.

**TERTIARY WINDING** - Winding added to a transformer in addition to the conventional primary and secondary windings such as for suppressing third harmonics or for making connections to a power-factor correcting device.

**TESLA COIL** - An induction coil used to develop a high frequency, high voltage discharge.

**TEST LEAD** - Flexible insulated lead used chiefly for connecting meters and test instruments to a circuit under test.

**TEST PROD** - Sharp metal point provided with an insulated handle and means for electrically connecting the point to a test lead. It is used for making touch connection to a circuit terminal.

**TEST SET** - Item of communications-electronics equipment which is used to locate faults and troubles in circuits and equipment.

**TETRODE** - Four-electrode electron tube containing an anode, a cathode, a control electrode, and one additional electrode, ordinarily in the nature of a grid.

**THERMAL AGITATION** - Movements of the free electrons in a material, due to heat. In a conductor, they produce minute pulses of current. When these occur at the input of a high-gain amplifier, the fluctuations are amplified together with signal currents and heard as noise.

**THERMIONIC EMISSION** - (1) Liberation of electrons due to the temperature rise of a cathode alone, quite independent of any other electrodes within the tube. (2) Electron emission from a solid body as a result of its elevated temperature.

**THERMISTOR** - An electronic device which makes use of the change of resistivity of a semiconductor with changes in temperature.

**THERMOCOUPLE** - Device consisting of two dissimilar metals in physical contact, thereby forming a thermojunction across which a voltage is developed when the junction is heated. An instrument comprising a thermocouple, or thermocouples, connected to a meter calibrated in units of temperature is one of many types of pyrometers (used to measure high temperatures). A thermocouple heated by RF current and connected to a DC meter serves as an RF ammeter when the meter is calibrated in current, and as an RF voltmeter when the meter is calibrated in volts.

**THREE-PHASE CIRCUIT** - Combination of circuits energized by alternating electromotive forces which differ in phase by one-third cycle or 120 electrical degrees. NOTE: In practice, the phase may vary several degrees from the specified angle.

**THRESHOLD** - Point at which an effect is first produced, observable or otherwise indicated.

**THYRATRON** - Hot-cathode gas-discharge tube in which one or more electrodes are employed to control electrostatically (with grids) the starting of the unidirectional current flow. Used as controlled rectifiers for electronic switches that close a circuit.

**THYRISTOR** - Bistable semiconductor device comprising three or more junctions. At least one junction can switch between reverse and forward polarity within a single quadrant of the anode-to-cathode voltage-current characteristics. Generically, the term includes silicon controlled rectifiers, gate control switches, and multi-layer two-terminal devices.

**THYRITE** - Silicon carbide ceramic material having nonlinear resistance characteristics. Above a critical voltage, the resistance falls considerably.

**TICKLER COIL** - Small coil connected in series with the collector or plate circuit of a transistor or tube, and inductively coupled to a base or grid-circuit coil in order to establish feedback or regeneration. Used chiefly in regenerative detector circuits.

**TIGHT COUPLING** - (1) Degree of coupling in which practically of of the magnetic lines of force produced by one coil, link a second coil. (2) More than enough coupling to give maximum transfer of energy at the resonant frequency. Greater than optimum coupling.

**TIME CONSTANT** - Time required for an exponential quantity to change by an amount equal to 0.632 times the total change that will occur. In a capacitor-resistor circuit, it is the number of seconds required for the capacitor to reach 63.2 percent of its full charge after a voltage is applied. In an inductor-resistor circuit, it is the number of seconds required for the current to reach 63.2 percent of its final value. The time constant in seconds of an inductor having an inductance L in henrys and resistance R in ohms is L/R. The time constant of a capacitor having a capacitance of C in farads in series with a resistance R in ohms is RC.

**TIME-DELAY CIRCUIT** - Circuit that delays the transmission of an impulse, signal, or performance; a definite desired period of time.

**TIMER** - (1) Assembly of electric circuits and associated equipment which provides the following: trigger pulses, sweep circuits, intensifier pulses, gate voltages, blanking voltages, and power supplies. An important feature of a timer is that the various output events are synchronized with respect to each other. (2) Part of an electronic circuit which starts pulse transmission and synchronizes it with the beginning of indicator sweep, timing of gates, range markers, etc.

**TINNED WIRE** - Copper wire that has been coated during manufacture with a layer of tin or solder to prevent corrosion and simplify soldering of connections.

**TOGGLE SWITCH** - Two-position switch which may be flipped from side-to-side to open or close circuits.

**TOLERANCE** - (1) Maximum error or variation from the standard permissible in a measuring instrument. (2) Maximum electrical or mechanical variation from specifications which can be tolerated without impairing the operation of a device.

**TOROID** - An object having a shape similar to a doughnut.

**TOURMALINE** - Strongly piezoelectric natural or synthetic crystal.

**TRACE** - (1) Pattern that appears on the screen of a cathode-ray tube. (2) Visible line or lines appearing on the screen of a cathode-ray tube as a result of the deflection of the electron stream.

**TRACKING** - (1) Process of keeping a radio beam, or the cross hairs of an optical system, set on a target and determining the range of the target continuously. (2) Maintenance of proper frequency relations in circuits designed to be simultaneously varied by gang operations. (3) Condition in which all tuned circuits in a receiver follow accurately, throughout the tuning range, the frequency indicated by the tuning dial.

**TRANSCONDUCTANCE** - Of a field effect transistor, the change in drain current caused by a change in gate voltage divided by the change in gate voltage, with drain-to-source voltage constant. Of a vacuum tube, the change in plate current divided by the change in grid voltage that causes the change in plate current, plate voltage held constant. It is also called mutual conductance.

**TRANSDUCER** - Device by means of which energy can flow from one or more transmission systems to one or more other transmission systems. NOTE: Energy transmitted by these systems may be of any form (e.g., it may be electrical, mechanical, or acoustical), and it may be of the same form or different forms in the various input and output systems. Microphones or loudspeakers which convert mechanical vibrations or sound waves into electrical energy, and vice versa, are samples of a transducer.

**TRANSFORMER** - An electric device, without moving parts, which by electromagnetic induction transforms electric energy from one or more circuits to one or more other circuits at the same frequency, usually with changed values of voltage and current.

**TRANSIENT** - (1) Instantaneous surge of voltage or current which occurs as the result of a change from one steady-state condition to another. (2) Phenomenon which takes place in a system owing to a sudden change in conditions and which persists for a relatively short time after the change has occurred. (3) Distinct line or series of lines perpendicular to the direction of scanning produced in the recorded copy immediately following a sudden change in density. (4) A damped oscillatory quantity occurring in the output of a system as a result of a sudden change in input.

**TRANSISTOR** - An active semiconductor device with three or more electrodes.

**TRANSISTOR BASE** - A region which lies between an emitter and a collector of a transistor, into which minority carriers are injected.

**TRANSISTOR TESTER** - Test instrument to indicate condition of transistors used in electronic equipment.

**TRANSIT TIME** - The time taken for a charge carrier to transverse a given path.

**TRANSMISSION** - (1) Transfer of electric power from one location to another over conductors. (2) Dispatching of a signal, message, or other form of intelligence by means of wire, radio-telegraphy, telephony, or fascimile.

**TRANSMISSION LINE** - (1) Material structure forming a continuous path from one place to another, for directing the transmission of electromagnetic energy along this path. (2) Conductor or series of conductors used to carry electrical energy from a source to a load.

**TRANSMITTER** - (1) The apparatus for the production and modulation of radio-frequency energy for the purpose of radio communication. (2) A term applied to that part of a radio or radar set where the radio-frequency oscillations are generated and/or amplified. (3) Device for converting sound waves to electrical waves.

**TRAVELING-WAVE TUBE** - An electron tube in which a beam of electrons interacts continuously with a guided electromagnetic wave to produce amplification at ultra-high frequencies.

**TRIGGER** - (1) To start action by means of one circuit, in another circuit which then functions for a period of time under its own control. (2) Short pulse, either positive or negative, which can be used to set into motion a chain of events.

**TRIMMER CAPACITOR** - Variable capacitor assocated with another capacitor and used for fine adjustment of the total capacitance.

**TRIODE** - Three-electrode vacuum tube containing an anode, a cathode, and a control grid.

**TRISISTOR** - A new fast-switching semiconductor, consisting of an alloyed junction PNP device in which the collector is a conjugate emitter, that is capable of electron injection into the base.

**TRUE POWER** - Average value of power consumed by a circuit during one complete cycle of alternating current; apparent power multiplied by the circuit power factor.

**TUBE** - Vacuum tube, so named because of its oftentime tube-shaped glass or metal envelope.

**TUBE TESTER** - Test instrument designed to indicate the condition of vacuum tubes used in electronic equipment.

**TUNED CIRCUIT** - Circuit consisting of inductance and capacitance which can be adjusted for resonance at a desired frequency.

**TUNED-PLATE, TUNED-GRID OSCILLATOR** - Vacuum-tube oscillator which has resonant circuits in both its grid and plate circuits, with no inductive coupling between them.

**TUNNEL DIODE SEMICONDUCTOR** - A semiconductor consisting of a PN junction which has been especially constructed to optimize the characteristics desired. It has an extremely narrow junction and large impurity concentrations in both regions. In operation , the tunnel diode differs from other types of PN junctions in that it exhibits negative resistance and the current is carried by electrons that travel across the PN barrier by quantum mechanical tunneling.

**TURNS RATIO OF A TRANSFORMER** - Ratio of the number of turns in the primary winding to those in the secondary winding.

**UNBALANCED LINE** - Transmission line in which the voltage on the two conductors are not equal with respect to ground; e.g., a coaxial line.

**UNIDIRECTIONAL** - Flowing in only one direction, such as a direct current.

**UNIDIRECTIONAL ANTENNA** - Antenna that has a single, well-defined direction of maximum radiation intensity.

**UNIDIRECTIONAL CURRENT** - Current which has either all positive or all negative values.

**UNIPOLAR TRANSISTOR** - A transistor which utilizes charge carriers of only one polarity.

**UNITY COUPLING** - Perfect magnetic coupling between two coils, so that all magnetic flux produced by the primary winding passes through the entire secondary winding.

**UPPER SIDEBAND** - Higher of two frequencies or two groups of frequencies produced by a modulation process.

**VACUUM** - Condition where sufficient air has been removed from a container so that any remaining gas will not affect the characteristics of the device beyond an allowable amount. Theoretically, a perfect vacuum is an enclosed space from which all the air and gases have been removed; this is never attained in actual practice.

**VACUUM TUBE** - Device consisting of an evacuated enclosure containing a number of electrodes (two or more) in which conduction of electricity takes place, unaffected by the presence of gas or vapor.

**VACUUM-TUBE VOLTMETER** - Device utilizing the characteristics of a vacuum tube for measuring voltages.

**VALENCE** - Measure of the extent to which an atom is able to combine directly with other atoms. It is believed to depend on the number and arrangement of the electrons in the outermost shell of the atom.

**VALENCE BAND** - The range of energy states in the spectrum of a solid crystal in which lie the energies of the valence electrons which bind the crystal together.

**VARACTOR** - Two-terminal device in which the electrical characteristic of interest is a voltage dependent capacitance.

**VARIABLE INDUCTANCE** - Coil (inductor) in which inductance value can be varied.

**VARIABLE-MU-TUBE** - Vacuum tube in which the wires of the grid are irregularly spaced, to that at different points within the operating range, the grid exercises a different amount of control on the electron stream. This shifts the operating point from one section of its characteristic curve to another, thus changing the amplification factor

**VARIABLE RESISTOR** - Wire-wound or composition resistor, the value of which may be changed.

**VARIABLE TRANSFORMER** - Iron-core transformer having provisions for varying its output voltage over a limited range or continuously from zero to maximum output voltage, generally by means of a contact arm moving along exposed turns of the secondary winding.

**VARIAC** - Trade name for an autotransformer with a toroidal winding with a rotating carbon brush, giving a continuously-adjustable output voltage from zero to line voltage plus 17 percent.

**VARISTOR** - A 2-terminal resistive element composed of an electronic semiconductor and suitable contacts which has a markedly nonlinear volt-ampere characteristic. NOTE: Varistors may be divided into two groups, symmetrical and nonsymmetrical, based on the symmetry or nonsymmetry of the volt-ampere curve.

**VECTOR DIAGRAM**- Arrangment of vectors showing the relations between alternating quantities having the same frequency.

**VECTOR QUANTITY** - Quantity that has both magnitude and direction. Examples of physical quantities that are vectors are displacement, velocity, force, and magnetic intensity.

**VIBRATOR** - (1) Electromagnetic device which is used to change a continuous steady current into a pulsating current. (2) Vibrating reed, driven like a buzzer, with contacts arranged to supply direct current to two windings of a transformer so that alternating current is supplied from another winding to the load.

**VIDEO** - (1) Latin word meaning "I see." It is applied as a prefix to the name of the television parts or circuits which carry picture signals. (2) Radar or television signals which actuate the cathode-ray tube; frequencies extending from approximately 60 hertz to several megahertz. (3) Pertaining to the bandwidth and spectrum position of the signal resulting from television scanning. NOTE: In current usage video denotes a bandwidth in the order of megahertz and a spectrum position that goes with a DC carrier.

**VIDEO AMPLIFIER** - Wideband amplifier capable of amplifying video frequencies.

**VIDEO FREQUENCY** - (1) Band of frequencies extending from approximately 100 hertz to several megahertz. (2) Frequency of the voltage resulting from television scanning. Range from 0 to 4 megahertz or more.

**VIRTUAL CATHODE** - Electron cloud that forms around an outer grid in a thermionic vacuum tube when an inner grid is maintained at a slightly positive potential with respect to the cathode.

**VOICE COIL** - Moving coil which activates the diaphragm of a dynamic speaker.

**VOICE FREQUENCY** - Frequency lying within that part of the audio range which is employed for the transmission of speech. Voice frequencies used for commercial transmission of speech usually lie within the range of 200 to 3,500 hertz.

**VOLT** - Unit of electromotive force or electrical pressure. One volt is the pressure required to send 1 ampere of current through a resistance of 1 ohm.

**VOLTAGE** - (1) Term used to signify electrical pressure. Voltage is a force which causes current to flow through an electrical conductor. (2) Voltage of a circuit; the greatest effective difference of potential between any two conductors of the circuit concerned.

**VOLTAGE AMPLIFIER** - Amplifier designated primarily to increase the voltage of a signal.

**VOLTAGE DIVIDER** - Resistor which is connected across the output of a power source with mechanical provisions for connecting the local load circuits in parallel across part or all the resistor, thereby obtaining the desired voltage.

**VOLTAGE DOUBLER** - Voltage multiplier which separately rectifies each half cycle of the applied alternating voltage and adds the two rectified voltages to produce a direct voltage, the amplitude of which is approximately twice the peak amplitude of the applied alternating voltage.

**VOLTAGE DROP** - Difference in voltage between two points. It is the result of the loss of electrical pressure as a current flows through an impedance.

**VOLTAGE GRADIENT** - Uniform rate of voltage change across the resistive material.

**VOLTAGE NODE** - Point having zero voltage in a stationary wave system. A voltage node exists at the center of a half-wave antenna.

**VOLTAGE RATING** - Maximum sustained voltage that can safely be applied to an electrical device without risking the possibility of electrical insulation breakdown.

**VOLTAGE RATING OF A FUSE** - Root-mean-square AC voltage or the DC voltage at which it is designed to operate.

**VOLTMETER** - (1) Instrument for measuring potential difference; may be calibrated in volts, microvolts, millivolts, or kilovolts.

**VR TUBE** - Gas-filled electronic tube which has the property of maintaining a nearly constant voltage across its terminal over a considerable range of current through the tube. Used in electronic voltage regulators.

**WATT** - Practical unit of electric power. It is the power required to do work at the rate of 1 joule per second. There are 746 watts in 1 hoursepower.

**WATTAGE RATING** - Rating expressing the maximum power that a device can safely handle.

**WAVE** - Propagated disturbance, usually periodic such as a radio wave or sound wave. If the periodic motion is regular and recurring, the wave is said to be periodic; if not recurring, it is said to be aperiodic or damped.

**WAVEGUIDE** - (1) Broadly, a system of material boundaries capable of guiding electromagnetic waves. (2) Specifically, a transmission line comprising a hollow conducting tube within which electromagnetic waves may be propagated; or, a solid dielectric or dielectric-filled conductor for the same purpose.

**WAVEGUIDE CUTOFF FREQUENCY** - Frequency limit of propagation along a waveguide for waves of a given field configuration.

**WAVELENGTH** - Wavelength is the distance traveled in one period or cycle by periodic disturbance. It is the distance between corresponding phases of two consecutive waves of a wave train. A wavelength is the quotient of velocity divided by frequency.

**WAVESHAPE** - Graph of the wave as a function of time or distance.

**WHEATSTONE BRIDGE**- Null-type resistance-measuring circuit in which resistance is measured by direct comparison with a standard resistance.

**WIEN BRIDGE** - Network of resistors and capacitors which has voltage characteristics, with respect to frequency, similar to those of a tuned, inductance-capacitance circuit, used for measuring frequencies.

**WINDING** - One or more turns of wire forming a continuous coil for a transformer, rotating machine, or other device.

**WIRE** - Solid or stranded group of solid, cylindrical conductors having low resistance to current flow, with any associated insulation.

**WIRE-WOUND RESISTOR** - Resistor utilizing, as the resistance element, a length of high-resistance wire or ribbon wound on an insulating form.

**WIRING DIAGRAM** - Drawing that shows electrical equipment and/or component parts together with all the wiring that interconnects this equipment and/or parts.

**WORKING VOLTAGE** - Voltage rating. In an electrolytic capacitor, it is the highest voltage that can be applied continuously with safety.

**YAGI ANTENNA** - Type of directional antenna array, usually consisting of one driven one-half wavelength dipole section, one parasitically excited reflector, and several parasitically excited directors.

**ZENER BREAKDOWN** - Of a semiconductor diode, a breakdown that is caused by the field emission of holes and electrons in the depletion layer.

**ZERO BEAT** - Condition where two frequencies which are being mixed are exactly the same, therefore produce no beat note.

**ZERO-BIAS TUBE** - Vacuum tube which is so designed that it may be operated as a class B amplifier without applying a negative bias to its control grid.

## GRAPHIC SYMBOLS

### GENERAL

The symbols may be oriented in any manner with respect to each other without changing their meanings. Thus, symbols for antennas, ground, chassis, etc., may "point" in any direction convenient to the draftsman preparing the diagram. Associated equipment, such as measuring devices, are identified as such by using broken lines for both interconnections and symbols. Terminal symbols may not be used unless actually required.

### TYPES OF DIAGRAMS USING GRAPHIC SYMBOLS

1. BLOCK DIAGRAMS - Block diagrams consist of simple rectangles and circles with names, connected with single lines to show the general arrangement of the apparatus required to perform the desired function. Direction of power or signal flow is often indicated by arrows near lines, or arrowheads on the lines themselves.

2. SCHEMATIC DIAGRAMS - Schematic diagrams show all major components graphically, and their interconnections. Many schematics will indicate voltage and current values, as well as wave shapes, at specific points. Single-line schematics use single lines to interconnect components, even though two or more conductors are required.

3. WIRING DIAGRAMS - Wiring diagrams are complete, in that all terminals are identified; all socket numbers, color-coded leads, rotors of variable condensers, etc., are clearly shown. Sufficient detail and identification is included so that a competent technician who has no knowledge of the operation of the equipment can wire it properly.

### ADJUSTABLE

1. Continuously adjustable, variable

### AMPLIFIER

2. General
3. With two inputs
4. With two outputs
5. With adjustable gain
6. With associated attenuator
7. With associated power supply
8. With external feedback path

### Amplifier Letter Combinations

(May be used with amplifier symbols if needed for explanation.)

| | |
|---|---|
| BDG | bridging |
| BST | booster |
| CMP | compression |
| DC | direct current |
| EXP | expansion |
| LIM | limiting |
| MON | monitoring |
| PGM | program |
| PRE | preliminary |
| PWR | power |
| TRQ | torque |

### ANTENNA

9. General
10. Dipole
11. Loop
12. Counterpoise, antenna

### ARRESTER, LIGHTNING

13. General
14. Carbon block
15. Electrolytic or aluminum cell
16. Horn gap

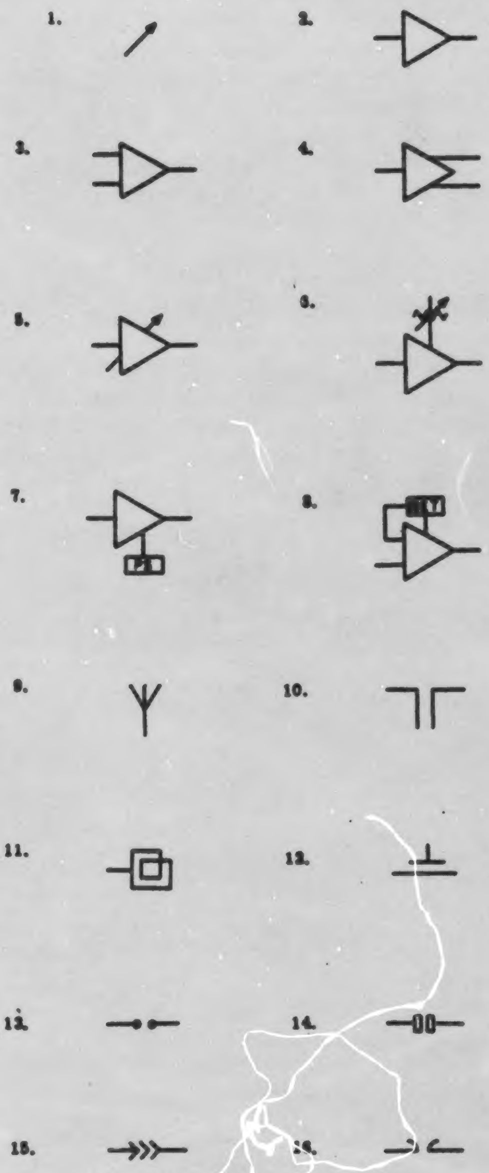


Table of Graphic Symbols

Tab'e of Graphic Symbols (contd)

### ARRESTER, LIGHTNING (Continued)

1. Protective gap
2. Sphere gap
3. Valve or film element
4. Multigap

### ATTENUATOR, FIXED

See also PAD (same symbols as variable attenuator without adjustment arrow.)

### ATTENUATOR VARIABLE

5. General
6. Balanced
7. Unbalanced

### AUDIBLE SIGNALING DEVICE

8. Bell
9. Buzzer
10. Loudspeaker

### Loudspeaker Letter Combinations

(Asterisk (*) and dagger (†) are not part of symbol.)

*HN horn, electrical
*HW howler
*LS loudspeaker
*SN siren
†EM electromagnetic with moving coil
†EMN electromagnetic, moving coil and neutralized winding
†MG magnetic armature
†PM permanent magnet

11. Sounder, telegraph

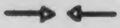
### BATTERY

12. One cell
13. Multicell
14. Multicell with taps
15. Multicell with adjustable tap

### CAPACITOR

16. General

1.



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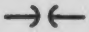

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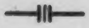

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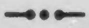

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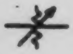

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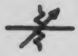

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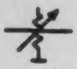

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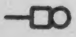

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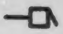

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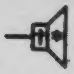

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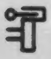

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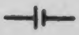

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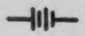

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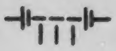

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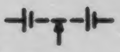

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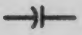


## Table of Graphic Symbols (Contd)

### CAPACITOR (Continued)

1. Polarised
2. Adjustable or variable
3. Adjustable or variable with mechanical linkage
4. Continously adjustable or variable differential
5. Phase shifter
6. Split stator
7. Feed-through

### CELL, PHOTOSENSITIVE

8. Asymmetrical photoconductive transducer
9. Symmetrical photoconductive transducer
10. Photovoltaic transducer

### CIRCUIT BREAKER

11. General

### CIRCUIT ELEMENT

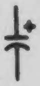
12. General

**Letter Combinations for Circuit Elements**

(*Asterisk not part of symbol.)

CLK clock
DIAL telephone dial
EQ equalizer
FAX facsimile set
FL filter
FL-BE filter, band elimination
FL-BP filter, band pass
FL-HP filter, high pass
FL-LP filter, low-pass
IND indicator
PS power supply
RU reproducing unit
RG recording unit
TEL telephone station
TPR teleprinter
TTY teletypewriter

1.



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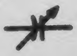

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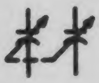

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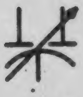

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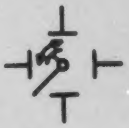

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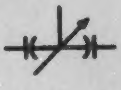

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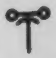

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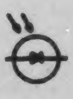

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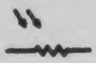

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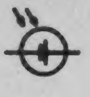

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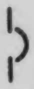

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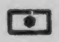

# Table of Graphic Symbols (Contd)

### Ground

1. Earth ground
2. Chassis connection
3. Common connections

(Identifying marks to denote points tied together shall replace (*) asterisks.)

### CLUTCH; BRAKE

4. Clutch disengaged when operating means deenergized
5. Clutch engaged when operating means deenergized
6. Brake applied when operating means energized
7. Brake released when operating means energized

### COIL, OPERATING (RELAY)

8. General
9. Dot shows inner end of winding

### CONNECTION, MECHANICAL (INTERLOCK)

10. Without fulcrum
11. With fulcrum

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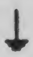

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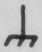

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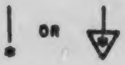

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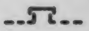

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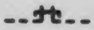

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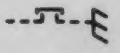

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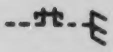

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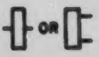

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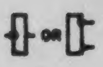

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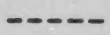

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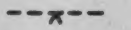


## Table of Graphic Symbols (Contd)

### CONNECTOR

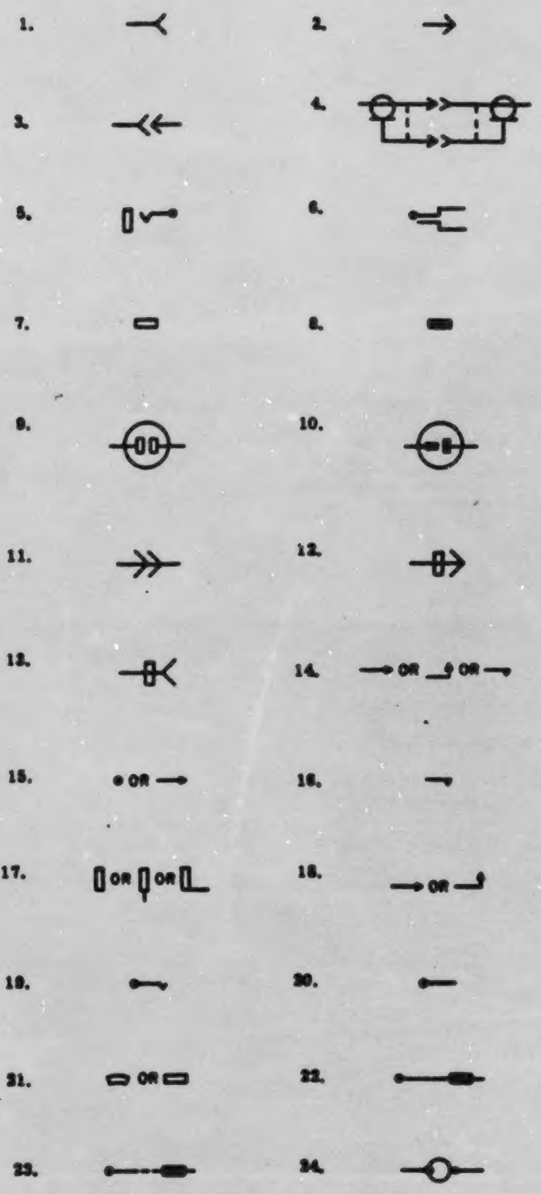
1. Female contact
2. Male contact
3. Separable connectors (engaged)
4. Coaxial connector with outside conductor carried through
5. Two-conductor switchboard jack
6. Two-conductor switchboard plug
7. Female contact (convenience outlets and mating connectors)
8. Male contact (convenience outlets and mating connectors)
9. Two-conductor nonpolarized connector with female contacts
10. Two-conductor polarized connector with male contacts

### Waveguide Flanges

11. Mated (general)
12. Plain (rectangular waveguide)
13. Choke (rectangular waveguide)

### CONTACT, ELECTRICAL

14. Fixed contact for jack, key or relay
15. Fixed contact for switch
16. Fixed contact for momentary switch
17. Sleeve
18. Moving contact, adjustable
19. Moving contact, locking
20. Moving contact, nonlocking
21. Segment, bridging contact
22. Vibrator reed
23. Vibrator split reed
24. Rotating contact (slip ring and contact)



**CONTACT, ELECTRICAL (Continued)**

1. Closed contact, break
2. Open contact, make
3. Transfer
4. Make-before-break
5. Open contact with time-closing or time-delay-closing
6. Closed contact with time-opening or time-delay-opening
7. Time-sequential-closing

**CORE**

Air core

No Symbol

8. Magnetic core of inductor or transformer
9. Core of magnet

10. **COUNTER, ELECTROMECHANICAL**

**COUPLER, DIRECTIONAL**

11. General
12. E-plane aperture coupling, 30-db loss
13. Loop coupling, 30-db loss
14. Probe coupling, 30-db loss
15. Resistance coupling, 30-db loss

16. **COUPLING**

(By aperture of less than waveguide size)

(Replace asterisk (*) by E, H or HE depending upon type of coupling to guided transmission path.)

**DELAY FUNCTION**

17. General
18. Tapped delay

(Replace asterisk (*) with value of delay.)

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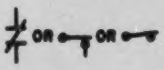

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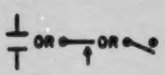

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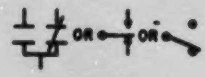

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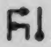

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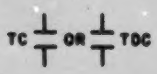

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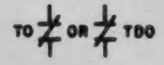

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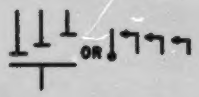

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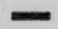

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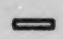

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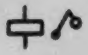

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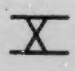

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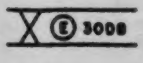

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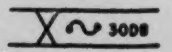

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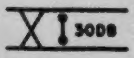

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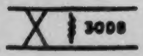

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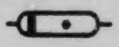

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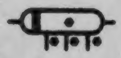


Table of Graphic Symbols (Contd)

**DIRECTION OF FLOW**

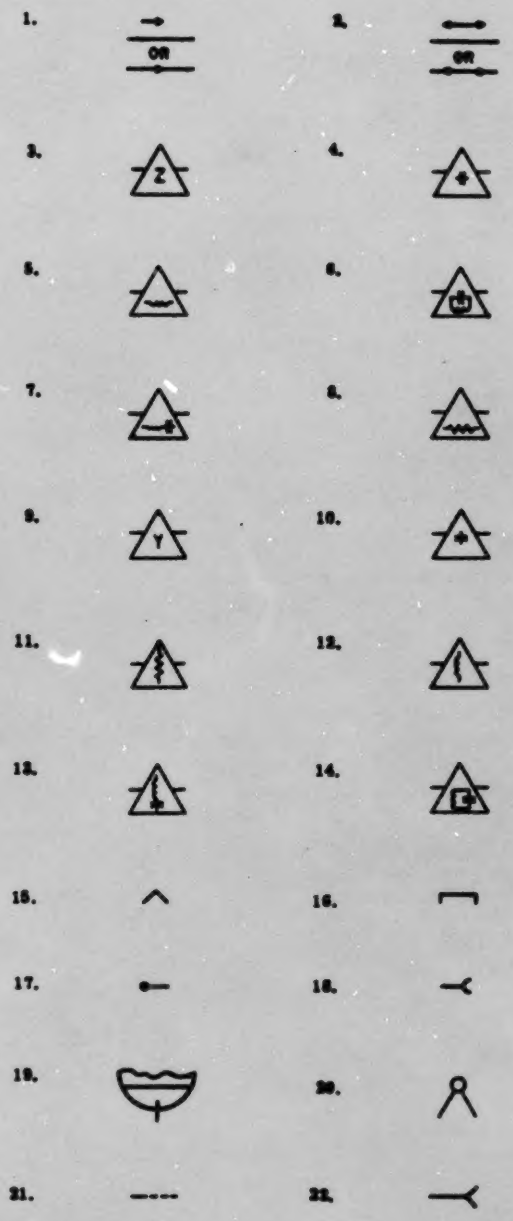
1. One way
2. Both ways

**DISCONTINUITY**

3. Equivalent series element
4. Capacitive reactance
5. Inductive reactance
6. Inductance-capacitance circuit, infinite reactance at resonance
7. Inductance-capacitance circuit, zero reactance at resonance
8. Resistance
9. Equivalent shunt element
10. Capacitive susceptance
11. Conductance
12. Inductive susceptance
13. Inductance-capacitance circuit with infinite susceptance at resonance
14. Inductance-capacitance circuit with zero susceptance at resonance

**ELECTRON TUBE**

15. Directly heated cathode, heater
16. Indirectly heated cathode
17. Cold cathode (Including ionically heated cathode)
18. Photocathode
19. Pool cathode
20. Ionically heated cathode with supplementary heating
21. Grid
22. Deflecting electrode



## Tab'e of Graphic Symbols (Contd)

### ELECTRON TUBE (Continued)

1. Ignitor
2. Excitor
3. Anode or plate
4. Target or x-ray anode
5. Dynode
6. Composite anode-photocathode
7. Composite anode-cold cathode
8. Composite anode-ionically heated cathode with supplementary heating
9. Shield, within envelope and connected to a terminal
10. Outside envelope of x-ray tube
11. Coupling by loop
12. Resonator, cavity type--single-cavity envelope with grid electrodes
13. Resonator--double-cavity envelope with grid electrodes
14. Multicavity magnetron anode and envelope
15. Envelope
16. Split envelope
17. Gas-filled envelope
18. Basing orientation, tubes with keyed bases
19. Basing, tubes with bayonets, bosses or other reference points
20. Base terminals

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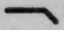

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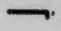

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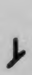

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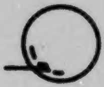

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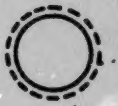

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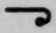

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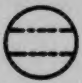

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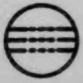

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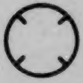

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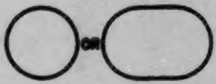

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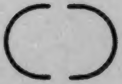

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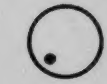

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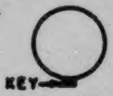

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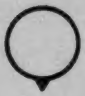

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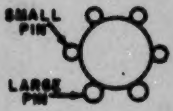

## Table of Graphic Symbols (Contd)

### ELECTRON TUBE (Continued)

1. Envelope terminals
2. Triode with directly heated cathode and envelope connection to base terminal
3. Pentode
4. Twin triode equipotential cathode
5. Cold-cathode voltage regulator
6. Vacuum phototube
7. Multiplier phototube
8. Cathode-ray tube, electrostatic deflection
9. Cathode-ray tube, magnetic deflection
10. Mercury-pool tube with ignitor and control grid
11. Mercury-pool tube with excitor, control grid and holding anode
12. Single-anode pool-type vapor rectifier with ignitor
13. Six-anode metal-tank pool-type rectifier with excitor
14. Resonant magnetron with coaxial output
15. Resonant magnetron with permanent magnet

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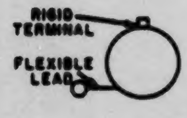

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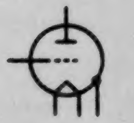

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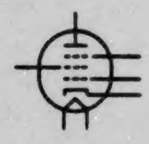

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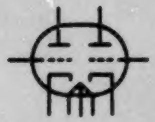

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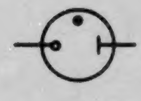

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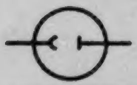

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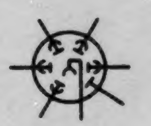

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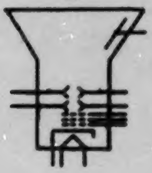

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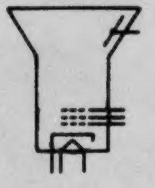

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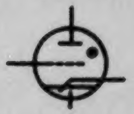

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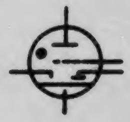

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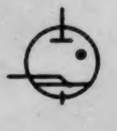

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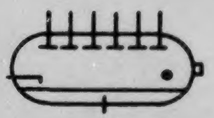

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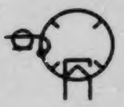

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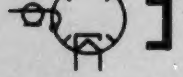

**ELECTRON TUBE (Continued)**

1. Tunable magnetron
2. Reflex klystron, integral cavity
3. Double-cavity klystron, integral cavity
4. Transmit-receive (t-r) tube
5. X-ray tube with directly heated cathode and focusing grid
6. X-ray tube with control grid
7. X-ray tube with grounded shield
8. Double-focus x-ray tube with rotating anode
9. X-ray tube with multiple accelerating electrode

**FUSE**

10. General
11. High-voltage fuse
12. High-voltage fuse, oil
13. **GOVERNOR**
14. **HALL GENERATOR**
15. **HANDSET**

**HYBRID**

16. General
17. Hybrid junction

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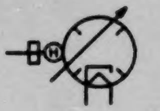

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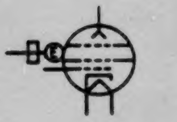

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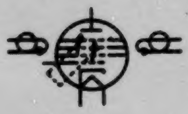

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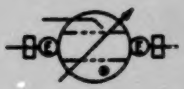

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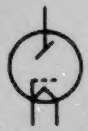

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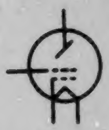

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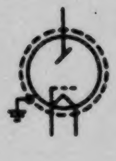

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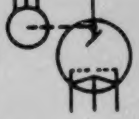

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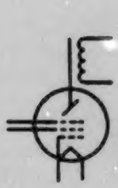

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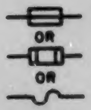

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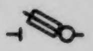

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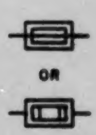

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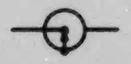

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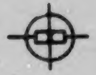

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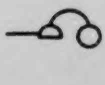

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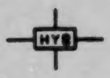

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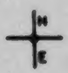

Table of Graphic Symbols (Contd)

**INDUCTOR**

1. General
2. Magnetic-core inductor
3. Tapped inductor
4. Adjustable inductor
5. Continuously adjustable inductor
6. Saturable-core inductor (reactor)
7. **KEY, TELEGRAPH**

**LAMP**

8. Ballast tube
9. Fluorescent lamp, two-terminal
10. Fluorescent lamp, four terminal
11. Cold-cathode glow lamp, AC type
12. Cold-cathode glow lamp, DC type
13. Incandescent lamp

**MACHINE, ROTATING**

14. Generator
15. Motor
16. **MAGNET, PERMANENT**
17. **METER**

**Meter Letter Combinations**

(Replace asterisk (*) with proper letter combination.)

A ammeter
AH ampere-hour
CMA contact-making (or breaking) ammeter
CMC contact-making (or breaking) clock
CMV contact-making (or breaking) voltmeter
CRO cathode-ray oscilloscope
DB decibel meter
DBM decibels referred to one milliwatt
DM demand meter
DTR demand-totalizing relay
F frequency meter

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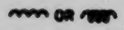

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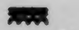

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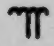

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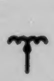

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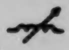

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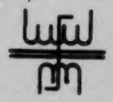

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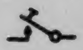

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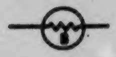

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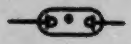

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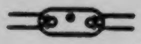

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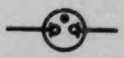

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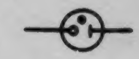

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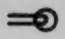

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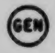

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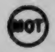

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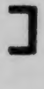

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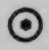
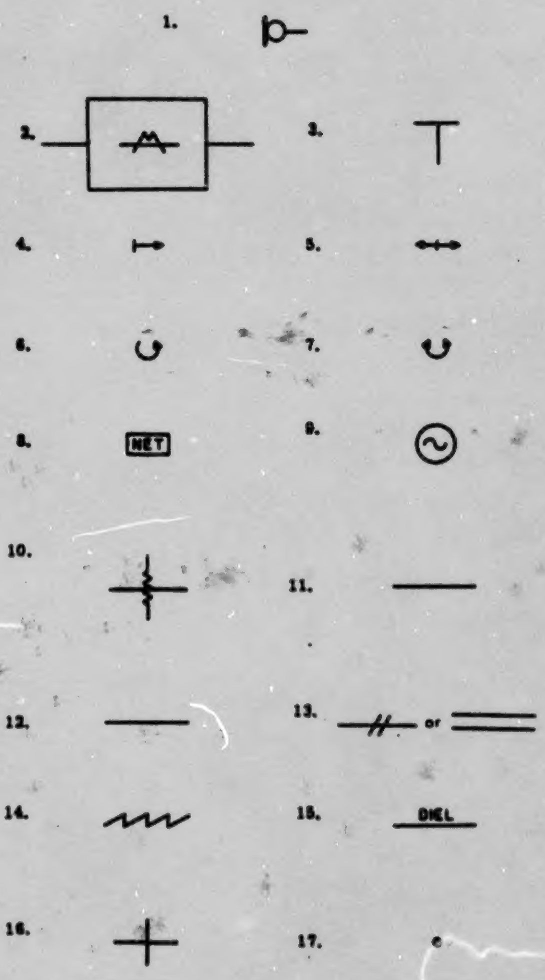


## Table of Graphic Symbols (Contd)

**Meter Letter**
**Combinations (Continued)**

G galvanometer
GD ground detector
I indicating
INT integrating
µA or UA microammeter
MA milliammeter
NM noise meter
OHM ohmmeter
OP oil pressure
OSCG oscillograph, string
PH phasemeter
PI position indicator
PF power factor
RD recording demand meter
REC recording
RF reactive factor
SY synchroscope
t° temperature
THC thermal converter
TLM telemeter
TT total time
V voltmeter
VA volt-ammeter
VAR varmeter
VARH varhour meter
VI volume indicating
VU standard volume indicating
W wattmeter
WH watthour meter



1. MICROPHONE
2. MODE SUPPRESSION
3. MODE TRANSDUCER

MOTION, MECHANICAL

4. Translation, one direction
5. Translation, both directions
6. Rotation, one direction
7. Rotation, both directions
8. NETWORK
9. OSCILLATOR
10. PAD

PATH, TRANSMISSION

11. General
12. Wire
13. Two conductors
14. Air or space path
15. Dielectric path other than air
16. Crossing of conductors not connected
17. Junction

## Table of Graphic Symbols (Contd)

### PATH, TRANSMISSION (Continued)

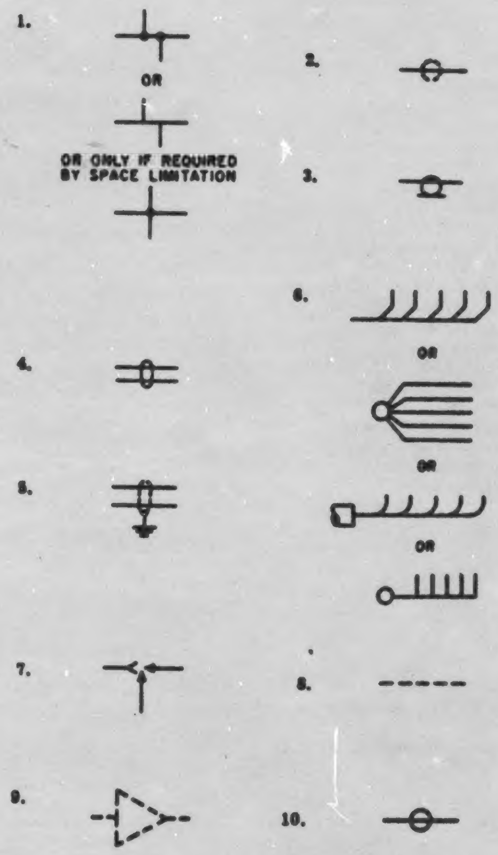
1. Junction of connected paths, conductors or wires
2. Shielded single-conductor cable
3. Coaxial cable
4. Two-conductor cable
5. Shielded two-conductor cable with shield grounded
6. Grouping of leads
7. Alternate or conditional wiring
8. Associated or future wiring
9. Associated or future equipment (amplifier shown)
10. Circular waveguide
11. Rectangular waveguide

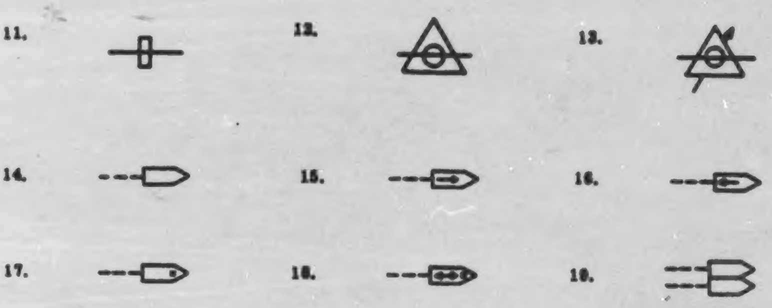
### PHASE SHIFTER

12. General
13. Adjustable

### PICKUP HEAD

14. General
15. Recording
16. Playback
17. Erasing
18. Writing, reading and erasing
19. Stereo





## Tab'e of Graphic Symbols (Contd)

1. **PIEZOELECTRIC CRYSTAL**

**POLARITY**

2. **Positive**
3. **Negative**

**RECEIVER, TELEPHONE**

4. **General**
5. **Headset**

**RECTIFIER**

**(Represents any method of rectification such as electron tube, solid-state device, electrochemical device, etc.)**

6. **General**
7. **Controlled** (N-Type Gate)

**RELAY**

8. **Alternating current or ringing**
9. **Fast-operate**
10. **Fast-release**
11. **Magnetically polarised**
12. **Slow-operate**
13. **Slow release**

**Relay Letter Combinations**

**(Not required with specific symbol.)**

**AC alternating current**
**D differential**
**DB double biased**
**DP dashpot**
**EP electrically polarised**
**FO fast operate**
**FR fast release**
**MG marginal**
**NB no bias**
**NR nonreactive**
**P magnetically polarised**
**SA slow operate and slow release**
**SO slow operate**
**SR slow release**
**SW sandwich wound**

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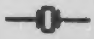

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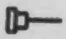

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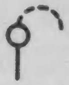

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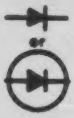

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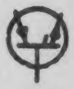

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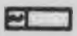

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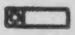

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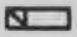

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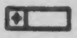

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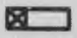

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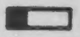

## Table of Graphic Symbols (Contd)

**RESISTOR**

1. General
2. Tapped resistor
3. Tapped resistor with adjustable contact
4. Adjustable or continuously adjustable
5. Instrument or relay shunt
6. Nonlinear resistor
7. Symmetrical varistor

(Replace asterisks (*) with identification of symbol.)

8. **RESONATOR, TUNED CAVITY**

**ROTARY JOINT**

9. General (Replace asterisk (*) with transmission-path recognition symbol.)
10. Coaxial in rectangular waveguide
11. Circular in rectangular waveguide

**SEMICONDUCTOR DEVICES**

12. Semiconductor region with one ohmic connection
13. Semiconductor region with plurality of ohmic connections
14. Rectifying junction, P on N region
15. Rectifying junction, N on P region
16. Emitter, P on N region
17. Plurality of P emitters on N region
18. Emitter, N on P region
19. Plurality of N emitters on P region
20. Collector

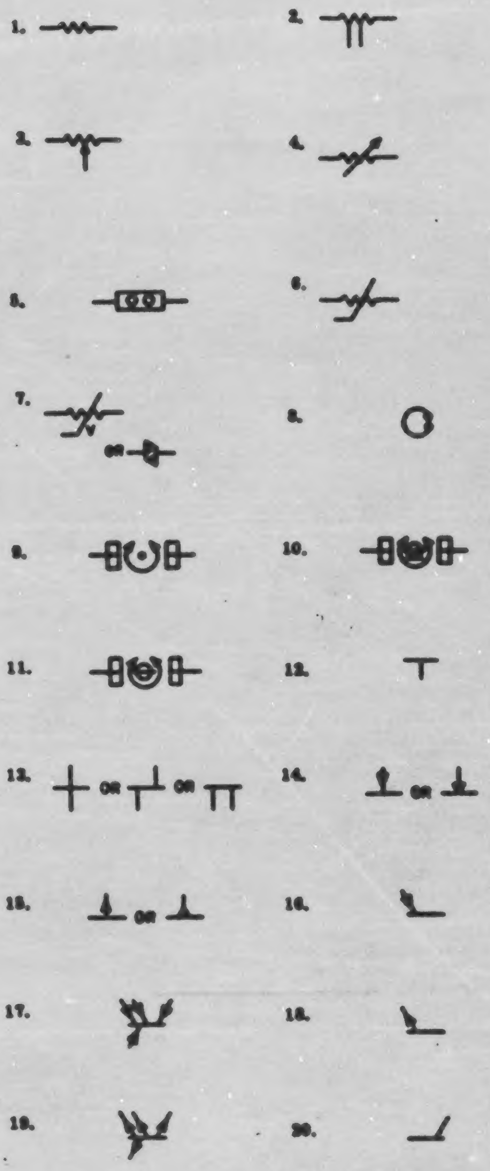

Table of Graphic Symbols (Contd)

### SEMICONDUCTOR DEVICES (Continued)

1. Plurality of collectors
2. Transition between regions of dissimilar conductivity
3. Intrinsic region between regions of dissimilar conductivity
4. Intrinsic region between regions of similar conductivity
5. Intrinsic region between collector and region of dissimilar conductivity
6. Intrinsic region between collector and region of similar conductivity
7. Light dependence
8. Temperature dependence
9. Capacitive device
10. Tunneling device
11. Breakdown device
12. PNP transistor (actual device and construction of symbol)
13. PNINIP device (actual device and construction of symbol)
14. Semiconductor diode
15. Capacitive diode (also: Varicap, varactor, reactance diode, parametric diode)
16. Breakdown diode, unidirectional (also: backward diode, avalanche diode, voltage regulator diode, zener diode, voltage reference diode)
17. Breakdown diode, bidirectional and backward diode (also: bipolar voltage limiter)
18. Tunnel diode (also esaki diode)

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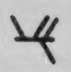

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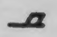

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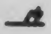

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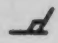

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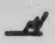

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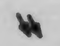

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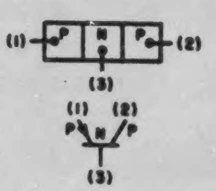

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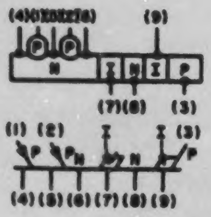

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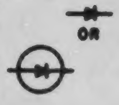

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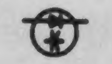

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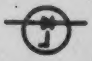

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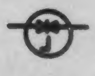

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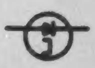
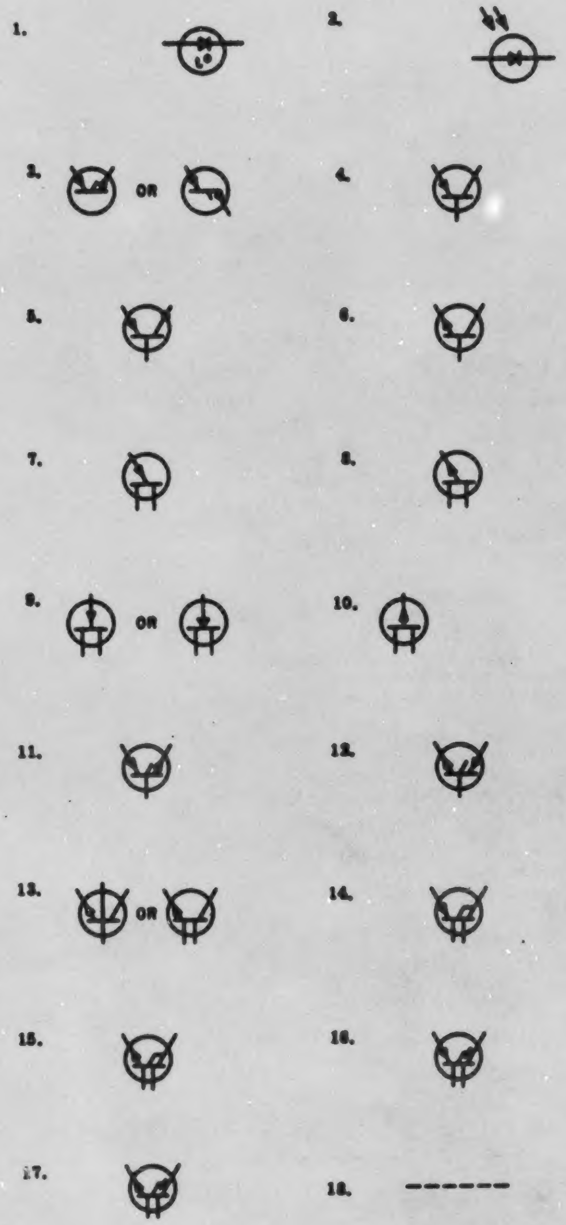


## Table of Graphic Symbols (Contd)

### SEMICONDUCTOR DEVICES (Continued)

1. Temperature dependent diode
2. Photodiode (also: solar cell)
3. Semiconductor diode, PNPN switch (also: Shockley diode, four-layer diode)
4. PNP transistor (also: junction, point-contact, mesa, epitaxial, planar, surface-barrier)
5. PNP transistor with one electrode connected to envelope
6. NPN transistor (see other names under PNP transistor)
7. Unijunction transistor, N-type base (also: double-base diode, filamentary transistor)
8. Unijunction transistor, P-type base (see other names above)
9. Field-effect transistor, N-type base
10. Field-effect transistor, P-type base
11. Semiconductor triode, PNPN Switch (also: controlled rectifier)
12. Semiconductor triode, NPNP Switch (also: controlled rectifier)
13. NPN transistor with transverse-biased base
14. PNIP transistor with ohmic connection to intrinsic region
15. NPIN transistor with ohmic connection to intrinsic region
16. PNIN transistor with ohmic connection to intrinsic region
17. NPIP transistor with ohmic connection to intrinsic region
18. SHIELD



## Table of Graphic Symbols (Contd)

### SQUIB

1. Explosive
2. Igniter
3. Sensing link

### SWITCH

4. Single-throw
5. Double-throw
6. Double-pole, double-throw with terminals shown
7. Knife switch
8. Push button, circuit closing (make)
9. Push button, circuit opening (break)
10. Nonlocking; momentary or spring return--circuit closing (make)
11. Nonlocking; momentary or spring return--circuit opening (break)
12. Nonlocking; momentary or spring return--transfer
13. Locking--circuit closing (make)
14. Locking--circuit opening (break)
15. Locking--transfer, three-position
16. Wafer (example shown: 3-pole, 3-circuit with 2 nonshorting and 1 shorting moving contacts)
17. Safety interlock--circuit opening
18. Safety interlock--circuit closing

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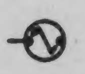

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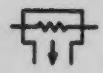

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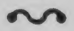

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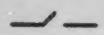

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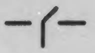

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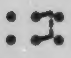

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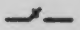

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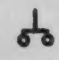

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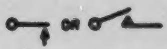

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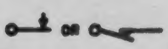

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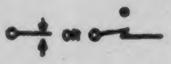

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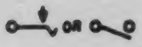

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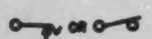

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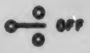

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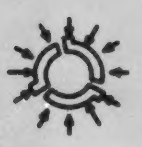

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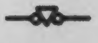

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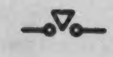

## Table of Graphic Symbols (Contd)

### SWITCHING FUNCTION

1. Conducting, closed contact (break)
2. Nonconducting, open contact (make)
3. Transfer

### SYNCHRO

4. General

### Synchro Letter Combinations

CDX control-differential transmitter

CT control transformer

CX control transmitter

TDR torque-differential receiver

TDX torque-differential transmitter

TR torque receiver

TX torque transmitter

RS resolver

B outer winding rotatable in bearings

### TERMINATION

5. Cable
6. Open circuit
7. Short circuit
8. Movable short
9. Terminating series capacitor, path open
10. Terminating series capacitor, path shorted
11. Terminating series inductor, path open
12. Terminating series inductor, path shorted
13. Terminating resistor
14. Series resistor, path open
15. Series resistor, path shorted

### THERMAL ELEMENT

16. Actuating device

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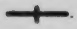

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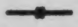

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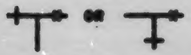

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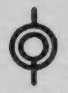

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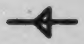

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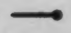

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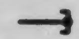

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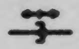

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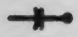

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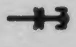

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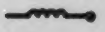

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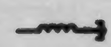

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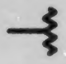

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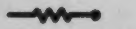

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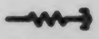

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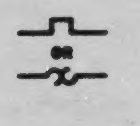

## Table of Graphic Symbols (Contd)

### THERMAL ELEMENT (Continued)

1. Thermal cutout
2. Thermal relay
3. Thermostat (operates on rising temperature), with break contact
4. Thermostat with make contact
5. Thermostat with integral heater and transfer contacts

### THERMISTOR

6. General
7. With integral heater

### THERMOCOUPLE

8. General
9. With integral heater internally connected
10. With integral insulated heater
11. Semiconductor thermocouple temperature measuring
12. Semiconductor thermocouple, current measuring

### TRANSFORMER

13. General
14. Transformer with polarity marks (instantaneous current in to instantaneous current out)

### VIBRATOR

15. Shunt drive
16. Separate drive

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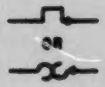

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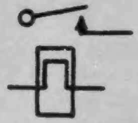

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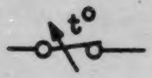

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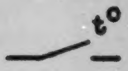

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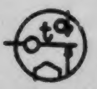

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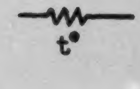

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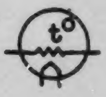

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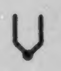

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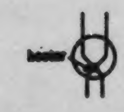

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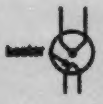

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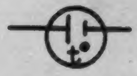

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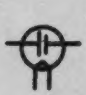

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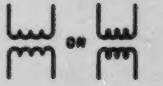

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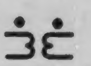

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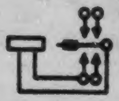

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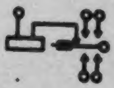

## Table of Graphic Symbols (Contd)

### VISUAL SIGNALING DEVICE

1. Annunciator, general
2. Annunciator drop or signal, shutter type
3. Annunciator drop or signal, ball type
4. Manually restored drop
5. Electrically restored drop
6. Switchboard-type lamp
7. Indicating lamp
8. Jeweled signal light

### Indicating Light Letter Combinations

(Replace asterisk (*) with proper letter combination.)

A amber
B blue
C clear
G green
NE neon
O orange
OP opalescent
P purple
R red
W white
Y yellow

### Logic Symbols

9. And
10. Or
11. Exclusive or
12. State Indicator
13. Flip-Flop Complementary

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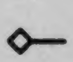

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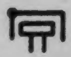

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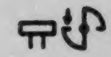

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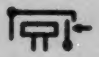

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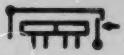

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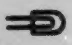

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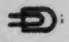

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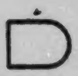

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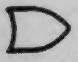

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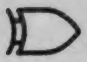

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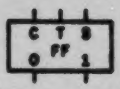

## Table of Graphic Symbols (Contd)

1. **Flip-Flop Latch**
2. **Single Shot**
3. **Schmitt Trigger**
4. **Amplifier**
5. **Time Delay**
6. **Oscillator**
7. **Logic Functions not otherwise Symbolized**

**(Replace asterisk (*) with abbreviation or complete indentification.)**

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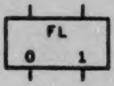

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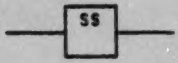

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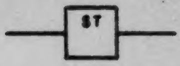

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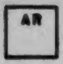

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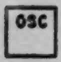

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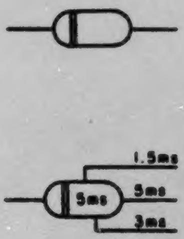

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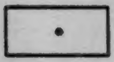

## ELECTRONIC FORMULAS AND LAWS

### OHM'S LAW FOR DC CIRCUITS

**Formulas**

When two DC circuit values are given, the unknown value may be determined by the application of the Ohm's Law formulas for DC circuits:

$$I = \frac{E}{R} \qquad I = \frac{P}{E} \qquad I = \sqrt{\frac{P}{R}}$$

$$E = IR \qquad E = \frac{P}{I} \qquad E = \sqrt{PR}$$

$$R = \frac{E}{I} \qquad R = \frac{E^2}{P} \qquad R = \frac{P}{I^2}$$

$$P = EI \qquad P = I^2R \qquad P = \frac{E^2}{R}$$

where I = current in amperes

E = potential in volts

R = resistance in ohms

P = power in watts

### 1. CURRENT FORMULAS

$$I = \frac{E}{R}$$

a. Total Current In Parallel Circuit

$$I_t = I_1 + I_2 + \ldots I_n$$

b. Total Current in Series Circuit

$$I_t = I_1 = I_2 = \ldots I_n$$

### 2. VOLTAGE FORMULAS

a. Impressed Voltage or Voltage Drop

$$E = IR$$

b. Total Voltage Across Parallel Circuit

$$E_t = E_1 = E_2 = \ldots : E_n$$

c. Total Voltage Across Series Circuit

$$E_t = E_1 + E_2 + \ldots E_n$$

### 3. RESISTANCE FORMULAS

a. Resistance Showing Variation With Material and Size

$$R = \frac{KL}{A}$$

K = resistivity

L = mean length

A = cross-section area in same units as L

b. Resistance to Current Flow

$$R = \frac{E}{I}$$

c. Two Resistors in Parallel

$$R_t = \frac{R_1 R_2}{R_1 + R_2}$$

d. Resistance Value Determined With a Voltmeter

$$R = \frac{E_a R_m}{E_m} - R_m$$

$E_a$ = voltage applied

$R_m$ = internal resistance

$E_m$ = voltmeter reading

e. Total Resistance of Series Circuit

$$R_t = R_1 + R_2 + \ldots R_n$$

f. Total Resistance of Parallel Circuit

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}}$$

4. POWER FORMULAS

a. Watts (Power, DC Circuit)

$$P = EI = I^2R = \frac{E^2}{R}$$

b. Total Power in Watts ($P_t$) Supplied to Circuits That Are in Parallel

$$P_t = P_1 + P_2 + \ldots P_n$$

$P_1$ = power in circuit 1 (watts)

$P_2$ = power in circuit 2 (watts)

$P_n$ = power in circuit$_n$ (watts)

5. EFFICIENCY FORMULA

$$N = \frac{\text{output}}{\text{input}} \times 100$$

6. CONDUCTANCE FORMULAS

a. Conductance for DC Circuits Is Expressed as the Reciprocal of Resistance

$$G = \frac{I}{R}$$

b. Ohm's Law Formulas When Conductance Is Considered

$$I = EG$$

$$R = \frac{I}{G}$$

$$E = \frac{I}{G}$$

where I = current (amperes)

E = voltage (volts)

G = conductance (mhos)

R = resistance (ohms)

c. When Resistors Are Connected in a Parallel DC Circuit, the Total Conductance Is Given By:

$$G_t = G_1 + G_2 + G_3 + G_4 \ldots$$

OHM'S LAW FOR AC CIRCUITS

Formulas

When two AC circuit values are given, the unknown value may be determined by the application of the Ohm's Law formulas for AC circuits. The following formulas are different variations in Ohm's Law for AC circuits:

$$I = \frac{E}{Z} \qquad I = \frac{P}{E\cos\theta} \qquad I = \sqrt{\frac{P}{Z\cos\theta}}$$

| Known Values | Formulas for Determining Unknown Values of . . . | | | |
|---|---|---|---|---|
| | I | R | E | P |
| I & R | | | IR | $I^2R$ |
| I & E | | $\frac{E}{I}$ | | IE |
| I & P | | $\frac{P}{I^2}$ | $\frac{P}{I}$ | |
| R & E | $\frac{E}{R}$ | | | $\frac{E^2}{R}$ |
| R & P | $\sqrt{\frac{P}{R}}$ | | $\sqrt{PR}$ | |
| E & P | $\frac{P}{E}$ | $\frac{E^2}{P}$ | | |

Figure 1. Ohm's Law Formulas for DC Circuit

$E = IZ \qquad E = \frac{P}{I\cos\theta} \qquad E = \sqrt{\frac{PZ}{\cos\theta}}$

$Z = \frac{E}{I} \qquad Z = \frac{E^2\cos\theta}{P} \qquad Z = \frac{P}{I^2\cos\theta}$

$P = EI\cos\theta \qquad P = I^2Z\cos\theta \qquad P = \frac{E^2\cos\theta}{Z}$

$P = I^2R$

where I = current in amperes

E = potential in volts

Z = impedance in ohms

R = resistance in ohms

P = power in watts

θ = phase angle in degrees

| Known Values | Formulas for Determining Unknown Values Of.... | | | |
|---|---|---|---|---|
| | I | Z | E | P |
| I & Z | | | IZ | $I^2\cos\Theta$ |
| I & E | | $\frac{E}{I}$ | | $IE\cos\Theta$ |
| I & P | | $\frac{P}{I^2\cos\Theta}$ | $\frac{P}{I\cos\Theta}$ | |
| Z & E | $\frac{E}{Z}$ | | | $\frac{E^2\cos\Theta}{Z}$ |
| Z & P | $\sqrt{\frac{P}{Z\cos\Theta}}$ | | $\sqrt{\frac{PZ}{\cos\theta}}$ | |
| E & P | $\frac{P}{E\cos\Theta}$ | $\frac{E^2\cos\Theta}{P}$ | | |

Figure 2. Ohm's Law Formulas for AC Circuits

## 1. CURRENT FORMULAS

**a. Alternating Current Flowing in Any AC Circuit**

$$I = \frac{E}{Z}$$

**b. Instantaneous Voltage (Sine Wave)**

$e = E_m \sin 2\pi ft$

$e \; 1 \; E_m \sin wt$

$E_m$ = maximum voltage (volts)

$f$ = frequency (hertz)

$t$ = time (seconds)

$w = 2\pi f$

**c. Average Current Value**

$I_{av} = 0.637 \, I_m$

$= 0.9 \, I_{eff}$

$I_m$ = maximum current (amperes)

$I_{eff}$ = effective current (amperes)

**d. Root-Mean-Square Current Value (Effective)**

$I_{rms} = 0.707 I_m$

$= 1.11 I_{av}$

$I_m$ = maximum current (amperes)

$I_{av}$ = average current (amperes)

**e. Maximum Current Values**

$I_m = 1.414 \, I_{eff}$

$= 1.57 I_{av}$

$I_{eff}$ = effective current (amperes)

$I_{av}$ = average current (amperes)

| CONVERT FROM | TO GET . . . | | | |
|---|---|---|---|---|
| | RMS Effective | Average | Peak | Peak-to-Peak |
| RMS (Effective) | | 0.900 | 1.414 | 2.828 |
| Average | 1.110 | | 1.570 | 3.141 |
| Peak | 0.707 | 0.637 | | 2.000 |
| Peak-to-Peak | 0.354 | 0.318 | 0.500 | |

Figure 3. Sine-Wave Voltage Conversion Factors

## 2. VOLTAGE FORMULAS

a. Alternating Voltage Dropped or Voltage Impressed Across Any Circuit

$$E = IZ$$

b. Alternating Voltage Drop or Voltage Impressed Across a Noninductive Resistor

$$E_r = IR$$

c. Alternating Voltage Drop or Voltage Impressed Across Inductor

$$E_L = IX_L$$

$X_L$ = reactance of inductor (ohms)

d. Alternating Voltage Drop or Voltage Impressed Across a Capacitor

$$E_c = IX_c$$

$X_c$ = reactance of capacitor (ohms)

e. Average Voltage Value

$$E_{av} = 0.637E_m = 0.9E_{eff} = 0.9E_{rms}$$

f. Root-Mean-Square, or Effective Voltage Value

$$E_{rms} = E_{eff} = 0.707E_m = \frac{E_m}{\sqrt{2}} = 1.11E_{av}$$

g. Maximum Voltage Value

$$E_m = 1.414E_{eff} = 1.57E_{av}$$

**3. POWER FACTOR FORMULAS** - The power factor of an AC circuit is equal to the ratio of the true power in watts to the apparent power in volt-amperes.

$$PF = \frac{\text{true watts}}{E \times I}$$

since $P = EI\cos\theta$

and $P_a = EI$

therefore $PF = \frac{EI\cos\theta}{EI}$

$$PF = \cos\theta$$

where PF = power factor

P = true power

$P_a$ = apparent power

$\theta$ = phase angle

a. For a Purely Resistive Circuit

$$\theta = 0°$$

$$PF = 1$$

b. For a Resonant Circuit

$$\theta = 0°$$

$$PF = 1$$

c. For a Purely Reactive Circuit

$$\theta = 90°$$

$$PF = 0$$

## 4. POWER (WATTS) FORMULAS

$$P = EI \times PF$$

PF = power factor

## ADMITTANCE FORMULAS:

a. Admittance of a Series Circuit

$$Y = \frac{1}{\sqrt{R^2 + X^2}}$$

b. Admittance Is Also Expressed as the Reciprocal of Impedance

$$Y = \frac{1}{Z} = \frac{I}{E}$$

where Y = admittance (mhos)

Z = impedance (ohms)

R = resistance (ohms)

I = current (amperes)

X = reactance (ohms)

E = potential (volts)

## 6. SUSCEPTANCE FORMULAS

a. Susceptance of a Series Circuit

$$B = \frac{X}{R^2 + X^2}$$

b. When the Resistance Is Zero, Susceptance Becomes the Reciprocal of Reactance

$$B = \frac{1}{X}$$

where B = susceptance (mhos)

X = reactance (ohms)

R = resistance (ohms)

**7. PHASE ANGLE FORMULAS** - The phase angle is the angle, expressed in degrees, by which the current lags the voltage in an inductive circuit, or leads the voltage in a capacitive circuit. For purely reactive circuits with no resistance (a theoretical concept) the current lags by 90° in an inductive circuit and leads by 90° in a capacitive circuit. Phase angle formulas for various combinations of R, $X_L$, and $X_c$ in series, parallel, and series-parallel circuits may be found in Figure 4.

a. RESONANT CIRCUIT - In a resonant circuit where $X_L = X_C$, the total impedance is resistive and the phase angle is 0°. Similarly, in a circuit consisting of resistance alone, the current and voltage are IN PHASE and the phase angle is 0°.

b. SERIES CIRCUITS - In series circuits containing reactance and resistance, the phase angle is equal to the angle whose tangent is indicated by the ratio $\frac{X}{R}$ and is expressed by

$$\theta = \text{arc tan}\,\frac{X}{R}$$

Where X = inductive or capacitive reactance in ohms

R = nonreactive resistance in ohms

arc tan = "the angle whose tangent is . . ."

c. PARALLEL CIRCUITS - In parallel circuits containing reactance and resistance, the phase angle is equal to the angle whose tangent is indicated by the ratio $\frac{R}{X}$ and is expressed by

$$\theta = \text{arc tan}\,\frac{R}{X}$$

## IMPEDANCE FORMULAS

When values for R, $X_L$, and $X_c$ are given, the impedance in ohms and the phase angle may be computed by the following formulas.

a. SERIES A C CIRCUIT - For a series a-c circuit:

$$Z = \sqrt{R^2 + X^2} \text{ and } \theta = \text{arc tan}\,\frac{X_L - X_c}{R}$$

b. PARALLEL AC CIRCUIT - For a parallel a-c circuit:

$$Z = \frac{1}{\sqrt{G^2 + B^2}}$$

$$\theta = \text{arc tan}\,\frac{RX_c - RX_L}{X_L X_c}$$

where Z = impedance in ohms

R = resistance of a circuit in ohms

$X = (X_L - X_c)$ = reactance of circuit in ohms

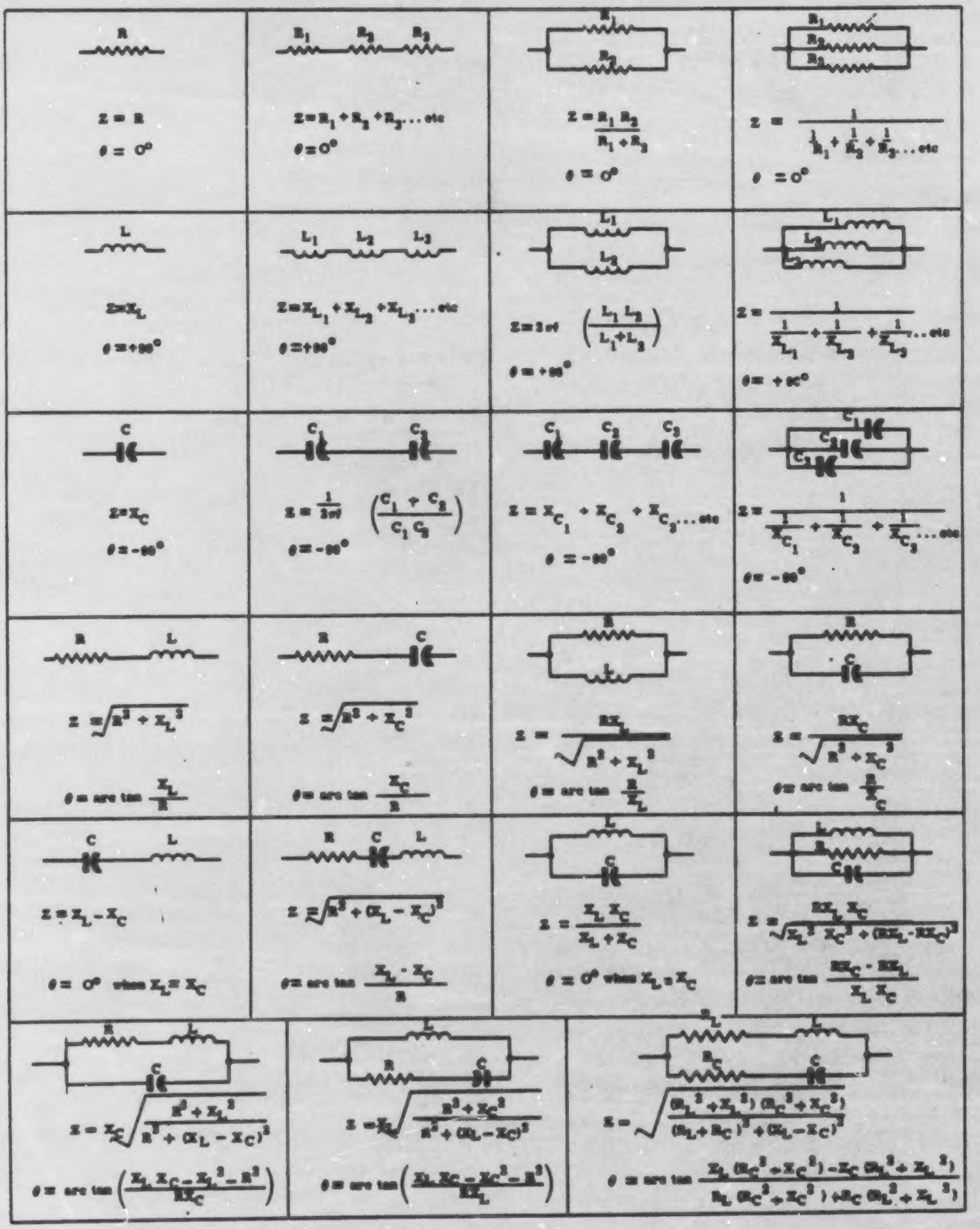
R
$Z = R$
$\theta = 0°$
$R_1$ $R_2$ $R_3$
$Z = R_1 + R_2 + R_3 \ldots \text{etc}$
$\theta = 0°$
$R_1$ $R_2$
$Z = \frac{R_1 R_2}{R_1 + R_2}$
$\theta = 0°$
$R_1$ $R_2$ $R_3$
$Z = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots \text{etc}}$
$\theta = 0°$
L
$Z = X_L$
$\theta = +90°$
$L_1$ $L_2$ $L_3$
$Z = X_{L_1} + X_{L_2} + X_{L_3} \ldots \text{etc}$
$\theta = +90°$
$L_1$ $L_2$
$Z = 2\pi f \left(\frac{L_1 L_2}{L_1 + L_2}\right)$
$\theta = +90°$
$L_1$ $L_2$ $L_3$
$Z = \frac{1}{\frac{1}{X_{L_1}} + \frac{1}{X_{L_2}} + \frac{1}{X_{L_3}} \ldots \text{etc}}$
$\theta = +90°$
C
$Z = X_C$
$\theta = -90°$
$C_1$ $C_2$
$Z = \frac{1}{2\pi f} \left(\frac{C_1 + C_2}{C_1 C_2}\right)$
$\theta = -90°$
$C_1$ $C_2$ $C_3$
$Z = X_{C_1} + X_{C_2} + X_{C_3} \ldots \text{etc}$
$\theta = -90°$
$C_1$ $C_2$ $C_3$
$Z = \frac{1}{\frac{1}{X_{C_1}} + \frac{1}{X_{C_2}} + \frac{1}{X_{C_3}} \ldots \text{etc}}$
$\theta = -90°$
R L
$Z = \sqrt{R^2 + X_L^2}$
$\theta = \text{arc tan} \frac{X_L}{R}$
R C
$Z = \sqrt{R^2 + X_C^2}$
$\theta = \text{arc tan} \frac{X_C}{R}$
R L
$Z = \frac{R X_L}{\sqrt{R^2 + X_L^2}}$
$\theta = \text{arc tan} \frac{R}{X_L}$
R C
$Z = \frac{R X_C}{\sqrt{R^2 + X_C^2}}$
$\theta = \text{arc tan} \frac{R}{X_C}$
C L
$Z = X_L - X_C$
$\theta = 0°$ when $X_L = X_C$
R C L
$Z = \sqrt{R^2 + (X_L - X_C)^2}$
$\theta = \text{arc tan} \frac{X_L - X_C}{R}$
L C
$Z = \frac{X_L X_C}{X_L + X_C}$
$\theta = 0°$ when $X_L = X_C$
L R C
$Z = \frac{R X_L X_C}{\sqrt{X_L^2 X_C^2 + (R X_L - R X_C)^2}}$
$\theta = \text{arc tan} \frac{R X_C - R X_L}{X_L X_C}$
R L C
$Z = X_C \sqrt{\frac{R^2 + X_L^2}{R^2 + (X_L - X_C)^2}}$
$\theta = \text{arc tan} \left(\frac{X_L X_C - X_L^2 - R^2}{R X_C}\right)$
L R C
$Z = X_L \sqrt{\frac{R^2 + X_C^2}{R^2 + (X_L - X_C)^2}}$
$\theta = \text{arc tan} \left(\frac{X_L X_C - X_C^2 - R^2}{R X_L}\right)$
$R_L$ L $R_C$ C
$Z = \sqrt{\frac{(R_L^2 + X_L^2)(R_C^2 + X_C^2)}{(R_L + R_C)^2 + (X_L - X_C)^2}}$
$\theta = \text{arc tan} \frac{X_L (R_C^2 + X_C^2) - X_C (R_L^2 + X_L^2)}{R_L (R_C^2 + X_C^2) + R_C (R_L^2 + X_L^2)}$

Figure 4. Impedance Chart

G = conductance of circuit in mhos

B = susceptance of circuit in mhos

$\theta$ = phase angle in degrees

## Q FACTOR FORMULAS

Q is a figure of merit which is widely used in the design of electronic equipment. The term may be applied to a single component, such as a coil or a capacitor, or it may be applied to an entire circuit composed of a number of resistive, inductive, or capacitive components. The Q factor is the ratio of reactance to resistance, and for an inductor or a circuit having inductance and resistance it is expressed as:

$$Q = \frac{X_L}{R_L}$$

CAPACITANCE AND RESISTANCE - For a capacitor or a circuit having capacitance and resistance.

$$Q = \frac{X_c}{R_c}$$

INDUCTANCE, CAPACITANCE, AND RESISTANCE - When a circuit contains a combination of inductive and capacitive reactance as well as resistance, the Q of such a circuit is usually expressed only at the resonant value of the reactances. Therefore:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

where Q = figure of merit

$X_L$ = inductive reactance in ohms

$X_c$ = capacitive reactance in ohms

$R_L$ = resistance in ohms in series with inductor or the R-L circuit

$R_c$ = resistance in ohms in series with capacitor or the R-C circuit

L = inductance in henrys

C = capacitance in farads

TUNED CIRCUIT - In a single tuned circuit, Q may be determined by the relationship between the resonant frequency and the bandwidth between the 3-db (half-power) points.

$$Q = \frac{f_r}{2\Delta f}$$

Q = figure of merit

$f_r$ = resonant frequency

$\Delta f$ = deviation from resonant frequency

$2\Delta f$ = bandwidth (width between the two half-power points)

## CAPACITY FORMULAS

### 1. TOTAL CAPACITY

a. Two Capacitors in Series:

$$C_t = \frac{C_1 C_2}{C_1 + C_2}$$

b. Total Capacitance of Capacitors in Parallel:

$$C_t = C_1 + C_2 + \ldots C_n$$

c. Total Capacitance of Capacitors in Series:

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \ldots \frac{1}{C_n}}$$

### 2. QUANTITY OF ELECTRICITY STORED IN A CAPACITOR:

$$Q = CE$$

where Q = quantity stored in coulombs

E = potential across the capacitor in volts

C = capacitance in farads

### 3. CAPACITANCE OF A PARALLEL PLATE CAPACITOR:

$$C = 0.08842 \frac{KS\,(N-1)}{d}$$

where C = capacitance in pf

K = dielectric constant (Figure 5)

S = area of one plate in square centimeters

N = number of plates

d = thickness of the dielectric in centimeters

| h'm | k | h'/m | k | m/h' | k |
|---|---|---|---|---|---|
| — | — | 0.3 | 0.280 | 1.0 | 0.207 |
| 0.02 | 0.463 | 0.4 | 0.261 | 0.9 | 0.203 |
| 0.04 | 0.384 | 0.5 | 0.247 | 0.8 | 0.196 |
| 0.06 | 0.369 | 0.6 | 0.236 | 0.7 | 0.190 |
| 0.08 | 0.356 | 0.7 | 0.227 | 0.6 | 0.184 |
| 0.10 | 0.346 | 0.8 | 0.219 | 0.5 | 0.177 |
| 0.15 | 0.323 | 0.9 | 0.2125 | 0.4 | 0.170 |
| 0.20 | 0.306 | 1.0 | 0.207 | 0.3 | 0.162 |
| 0.25 | 0.291 | — | — | 0.2 | 0.153 |
| 0.30 | 0.280 | — | — | 0.1 | 0.144 |
| — | — | — | — | 0 | 0.130 |

[1] Use either h'/m or m/h', whichever is less than unity.

Figure 5. Values of the Constant k

### 4. CAPACITANCE OF A SINGLE WIRE PARALLEL TO GROUND:

$$C = \frac{7.354L}{\log_{10}\frac{4h}{d} - S}$$

where C = capacitance in pf

L= length in feet

h = height above earth in feet

d = diameter of wire in feet

S = a constant (Figure 6)

| 2h/1 | S | 1/2h | S | 1/2h | S |
|---|---|---|---|---|---|
| 0 | 0 | 1.00 | 0.336 | 0.50 | 0.541 |
| 0.1 | 0.042 | 0.95 | 0.350 | 0.45 | 0.579 |
| 0.2 | 0.083 | 0.90 | 0.364 | 0.40 | 0.617 |
| 0.3 | 0.121 | 0.85 | 0.379 | 0.35 | 0.664 |
| 0.4 | 0.127 | 0.80 | 0.396 | 0.30 | 0.721 |
| 0.5 | 0.191 | 0.75 | 0.414 | 0.25 | 0.780 |
| 0.6 | 0.222 | 0.70 | 0.436 | 0.20 | 0.874 |
| 0.7 | 0.254 | 0.65 | 0.457 | 0.15 | 0.980 |
| 0.8 | 0.283 | 0.60 | 0.486 | 0.10 | 1.156 |
| 0.9 | 0.310 | 0.55 | 0.510 | 0.05 | 1.445 |
| 1.0 | 0.336 | 0.50 | 0.541 | | |

[1] Use either 2h/1 or 1/2h, whichever is less than unity.

Figure 6. Values for Constants S

### 5. CAPACITANCE TO GROUND OF PARALLEL WIRES OF THE SAME HEIGHT JOINED TOGETHER:

$$C = \frac{7.36L}{F}$$

where C = capacitance in pf

$$F = \frac{P + (n-1)Q}{n} - S_n$$

$$P = \log_{10}\frac{4h}{d} - S$$

$$Q = \log_{10}\frac{2h}{d} - S$$

L= length of wire (assumed same for all wires)

h = height above earth in feet

d = diameter of wire in feet

n = number of wires

D = spacing between adjacent wires (assumed to be the same for all adjacent pairs)

S = a constant (Figure 6)

$S_n$ = a constant (Figure 7)

NOTE: This formula assumes that the ratio D/d is large.

| n | $S_n$ | n | $S_n$ | n | $S_n$ |
|---|---|---|---|---|---|
| 2 | 0 | 10 | 0.420 | 18 | 0.647 |
| 3 | 0.067 | 11 | 0.450 | 19 | 0.665 |
| 4 | 0.125 | 12 | 0.480 | 20 | 0.686 |
| 5 | 0.197 | 13 | 0.500 | 30 | 0.847 |
| 6 | 0.233 | 14 | 0.540 | 40 | 0.979 |
| 7 | 0.283 | 15 | 0.570 | 50 | 1.063 |
| 8 | 0.347 | 16 | 0.601 | 100 | 1.337 |
| 9 | 0.380 | 17 | 0.625 | | |

Figure 7. Values for Constants $S_n$

6. CAPACITANCE TO GROUND OF A SINGLE VERTICAL WIRE:

$$C = \frac{7.36m}{\log_{10}\frac{2h'}{d} - k}$$

where C = capacitance in pf

m = length of vertical wire in feet

h' = height of lower end of wire above earth in feet

d = diameter of wire in feet

k = a constant (Figure 5)

INDUCTANCE FORMULAS

1. TOTAL INDUCTANCE:

a. Two Inductors in Parallel With No Mutual Inductance:

$$L_t = \frac{L_1 L_2}{L_1 + L_2}$$

b. Total Inductance of Inductors in Series With No Mutual Inductance:

$$L_t = L_1 + L_2 + \ldots L_n$$

c. Total nductance of Inductors in Parallel With No Mutual Inductance:

$$L_t = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \ldots \frac{1}{L_n}}$$

d. Total Inductance of Inductors in Series With Coupling Present:

$$L_t = L_1 + L_2 \pm 2M$$

Plus (+) for aiding

Minus (-) for opposing

L = inductance of coils (henrys)

M = mutual inductance of coils (henrys)

2. INDUCTIVE REACTANCE:

$$X_L = wL = 2\pi fL$$

f = frequency (hertz)

3. MUTUAL INDUCTANCE - The mutual inductance between two coupled r-f coils is given by

$$M = \frac{L_a - L_o}{4}$$

where M = mutual inductance

$L_a$ = total inductance of $L_1$ and $L_2$ with aiding fields

$L_o$ = total inductance of $L_1$ and $L_2$ with opposing fields

## 4. INDUCTANCE OF SMALL AIR-CORE COILS

a. Single-Layer Wound Coils:

$$L = \frac{(rN)^2}{9r + 10\ell} \quad \text{and} \quad N = \sqrt{\frac{L(9r + 10\ell)}{r}}$$

b. Multilayer Wound Coils:

$$L = \frac{0.8(rN)^2}{6r + 9l + 10b}$$

where L = self-inductance in microhenrys

N = total number of turns

r = mean radius in inches

$\ell$ = length of coil in inches

b = depth of coil in inches

## 5. COUPLING COEFFICIENT

When two r-f coils are inductively coupled, the coefficient of coupling is given by:

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

where K = coupling coefficient (K x 100 = coupling coefficient in percent)

M = mutual inductance

$L_1$, $L_2$ = self-inductance of coil

## TRANSFORMER FORMULAS

### 1. CURRENT:

a. Current-Turns Relationship in Transformer (Approximately):

$$\frac{I_{pri}}{I_{sec}} = \frac{T_{sec}}{T_{pri}}$$

$T_{pri}$ = primary turns

$T_{sec}$ = secondary turns

b. Current-Voltage Relationship in Transformer (Approximately):

$$\frac{I_{pri}}{I_{sec}} = \frac{E_{sec}}{E_{pri}}$$

### 2. VOLTAGE

Voltage-turns relationship in transformer (approximately):

$$\frac{E_{pri}}{E_{sec}} = \frac{T_{pri}}{T_{sec}}$$

$T_{pri}$ = primary turns

$T_{sec}$ = secondary turns

### 3. RESISTANCE

Resistance-Turns Relationship in Transformer (With Unity Coupling):

$$\frac{R_{pri}}{R_{sec}} = \left(\frac{T_{pri}}{T_{sec}}\right)^2 \quad \text{or} \quad \frac{T_{pri}}{T_{sec}} = \sqrt{\frac{R_{pri}}{R_{sec}}}$$

### 4. IMPEDANCE

Impedance-Turn Relationship in Transformer (With Unity Coupling):

$$\frac{Z_{pri}}{Z_{sec}} = \left(\frac{T_{pri}}{T_{sec}}\right)^2$$

or

$$\frac{T_{pri}}{T_{sec}} = \sqrt{\frac{Z_{pri}}{Z_{sec}}}$$

$T_{pri}$ = primary turns

$T_{sec}$ = secondary turns

$Z_{pri}$ = primary impedance (ohms)

$Z_{sec}$ = secondary impedance (ohms)

## FREQUENCY FORMULAS

Wavelength

$$\lambda = \frac{v}{f}$$

where $\lambda$ = wavelength

v = velocity of propagation

f = signal frequency

Time or Period:

$$t = \frac{1}{f_{\text{hertz}}}$$

where t = duration of one cycle in seconds

To Convert From Frequency to Wavelength:

$$\lambda_{\text{meters}} = \frac{3 \times 10^8}{f_{\text{hertz}}}$$

also $\lambda_{\text{meters}} = \dfrac{3 \times 10^5}{f_{\text{kilohertz}}}$

and $\lambda_{\text{meters}} = \dfrac{300}{f_{\text{megahertz}}}$

To Convert From Wavelength to Frequency:

$$f_{\text{hertz}} = \frac{3 \times 10^8}{\lambda}$$

also $f_{\text{kilohertz}} = \dfrac{3 \times 10^5}{\lambda}$

and $f_{\text{megahertz}} = \dfrac{300}{\lambda}$

where $\lambda$ = wavelength in meters

## RESONANCE FORMULAS

When $X_L$ is equal to $X_C$, the circuit is resonant at a particular frequency. Combining the two reactance formulas, the formula for resonant frequency is found to be:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ or } f_r = \frac{0.159}{\sqrt{LC}}$$

also $L = \dfrac{1}{(2\pi)^2 (f_r)^2 C}$

and $C = \dfrac{1}{(2\pi)^2 (f_r)^2 L}$

where $f_r$ = resonant frequency in hertz

L = inductance in henrys

C = capacitance in farads

$2\pi = 6.28$

$4\pi^2 = 39.5$

## VACUUM TUBE FORMULAS:

1. **PLATE RESISTANCE** - The dynamic plate resistance, $r_p$, of an electron tube is the resistance of the electron path between cathode and plate. It may be calculated by effecting a small change in plate voltage, and dividing this by the corresponding change in plate current, with the grid voltage held at a constant value. The dynamic plate resistance ($r_p$) in ohms is given by

$$r_p = \frac{\Delta E_p}{\Delta I_p}$$

with $E_g$ held constant.

2. **AMPLIFICATION FACTOR** - The amplification factor, $\mu$, of a vacuum tube is the ratio of the change in plate voltage to the opposite change in grid voltage required to maintain the plate current at a constant value. The numerical value of $\mu$ is given by

$$\mu = \frac{\Delta E_p}{\Delta E_g}$$

with $I_p$ held constant.

**3. TRANSCONDUCTANCE** - The transconductance, or mutual conductance, $g_m$, of a vacuum tube is equal to the amplification factor divided by the plate resistance. Therefore, the transconductance is equal to the change in plate current divided by the change in grid voltage, with the plate voltage held at a constant value. The transconductance ($g_m$) in mhos is given by

$$g_m = \frac{\mu}{r_p} = \frac{\Delta E_p/\Delta E_g}{\Delta E_p/\Delta I_p} \quad \text{or} \quad g_m = \frac{\Delta I_p}{\Delta E_g}$$

with $E_p$ held constant.

**4. VOLTAGE GAIN**

a. Grounded-Cathode Circuit - The voltage amplification, or voltage gain, of a vacuum tube in a grounded-cathode circuit is expressed by

$$A = \frac{\mu R_L}{R_L + r_p}$$

$$\text{also } A = \frac{g_m R_L r_p{}^*}{10^6 (R_L + r_p)}$$

In cases where $r_p \gg R_L$, the formula may be simplified to

$$A = g_m R_L$$

*In this formula, $g_m$ is expressed in micromhos.

b. Grounded-Grid Circuit - The voltage gain of a vacuum tube in a grounded-grid circuit is expressed by

$$A = (1 + \mu)\frac{R_L}{R_L + r_p}$$

c. Grounded-Plate Circuit - The voltage gain of a vacuum tube in a grounded-plate (cathode follower) circuit is given by

$$A = \frac{R_L}{r_p + (1 + \mu)R_L}$$

where rp = dynamic plate resistance in ohms

$E_p$ = plate voltage

$E_g$ = grid voltage

$I_p$ = plate current

$\mu$ = amplification factor

$g_m$ = transconductance in mhos (multiply by $10^6$ for transconductance in micromhos)

$R_L$ = load resistance in ohms

A = gain of tube

$\Delta$ = change of value, either increment or decrement

d. Amplifier With Feedback - The voltage gain of an amplifier with feedback is given by:

$$\text{Gain with feedback} = \frac{A}{1 - A\beta}$$

where A = gain of amplifier without feedback

$\beta$ = fraction of the output voltage which is feedback

NOTE: If the expression $1 - A\beta$ is less than unity, the feedback is said to be regenerative. This type of feedback, common in oscillator circuits, is not used in conventional amplifiers because of the distortion introduced by it. In amplifiers, therefore, the feedback is usually negative and the fractional part of the output voltage which is the feedback is $-\beta$. For negative feedback, then, the formula becomes

$$\text{Gain with negative feedback} = \frac{A}{1 + A\beta}$$

Hence, the expression $1 + A\beta$ is greater than unity and the feedback is degenerative. When the gain of the stage, A, is large compared with 1, the formula may be expressed by:

$$\text{Gain with negative feedback} = \frac{1}{\beta}$$

## TIME CONSTANT FORMULA

1. RC TIME CONSTANT - The time constant of an RC circuit is the time required to charge the capacitor to 63.2 percent of its final voltage or to discharge it to 36.8 percent of its initial charge. For calculating the time constant of an RC circuit, the following formulas may be used:

$$t(\text{sec}) = R(\text{ohms}) \times C(\text{farads})$$

$$t(\text{sec}) = R(\text{megohms}) \times C(\mu f)$$

$$t(\mu\text{sec}) = R(\text{ohms}) \times C(\mu f)$$

$$t(\mu\text{sec}) = R(\text{megohms}) \times C(\text{pf})$$

a. Steady-State Condition - For all practical purposes, the steady-state condition is reached after five time constants.

b. Used for Coupling - When used for coupling, an RC circuit should have a time constant at least 10 times longer than the period of the lowest frequency it must pass.

c. Used as a Differentiator - When used as a differentiator, an RC circuit should have a time constant not longer than 1/10 the period of the waveform to be peaked.

2. RL TIME CONSTANT - The time constant of an RL circuit is the time required for the current through the inductor to increase to 63.2 percent of its maximum value, or to decrease to 36.8 percent of its maximum value. For calculating the time constant of an RL circuit:

$$t(\text{sec}) = \frac{L(\text{henrys})}{R(\text{ohms})}$$

$$t(\mu\text{sec}) = \frac{L(\text{Microhenrys})}{R(\text{ohms})}$$

## TRANSMISSION LINE FORMULAS

### Coaxial Impedance

For characteristic impedance of a coaxial transmission line:

$$Z = 138 \left(\log_{10}\frac{d_1}{d_2}\right)$$

### Coaxial Resistance

For RF resistance in ohms per foot of a copper coaxial line:

$$r = \sqrt{f}\left(\frac{1}{d_1} + \frac{1}{d_2}\right) 10^{-3}$$

### Coaxial Attenuation

For attenuation in db per foot of coaxial line:

$$a = \frac{4.6\sqrt{f}\ (d_1 + d_2)}{d_1 d_2 \left(\log_{10}\frac{d_1}{d_2}\right)} \times 10^{-6}$$

where $Z$ = characteristic impedance in ohms

$r$ = RF resistance in ohms per foot of copper line

$a$ = attenuation in db per foot of line

$d_1$ = inside diameter of outer conductor in inches

$d_2$ = outside diameter of inner conductor in inches

$f$ = frequency in megahertz

### Two-Wire Line Impedance

For characteristic impedance of a two-wire open air transmission line:

$$Z = 276 \log_{10}\frac{2D}{d}$$

### Two-Wire Line Inductance

For inductance in microhenrys per foot of two-wire transmission line:

$$L = 0.281 \left( \log_{10} \frac{2D}{d} \right)$$

### Two-Wire Line Capacitance

For capacitance in pf per foot of two-wire transmission line:

$$C = \frac{3.68}{\log_{10} \frac{2D}{d}}$$

### Two-Wire Line Resistance

For RF resistance in ohms per loop-foot of wire:

$$R_f = \frac{2 \times 10^{-3} \sqrt{f}}{d}$$

### Two-Wire Line Attenuation

For attenuation in db per foot of wire:

$$db = \frac{0.0157 R_f}{\log_{10} \frac{2D}{d}}$$

where Z = characteristics impedance in ohms
D = spacing between wire centers in inches
d = diameter of conductors in inches
L = inductance in microhenrys per foot of line
C = capacitance in pf per foot of line
db = attenuation in db per foot of wire
$R_f$ = RF resistance in ohms per loop-foot of wire
f = frequency in megahertz

## NETWORK MATCHING AND ATTENUATING PAD

1. ATTENUATING PAD - Pad circuits can be computed using the network matching and attenuation nomograph as illustrated in Figures 8 and 9.

Conditions: $Z_1 = Z_2$, and $R_a = R_b$

a. With straightedge, connect Z on scale A to required db loss on scale C. Read $R_c$ on scale F.

b. Connect Z on scale A to required db loss on scale D. Read $R_a + R_c$ on scale F.

c. Subtract $R_c$ from the total, leaving $R_a$.

d. $R_a = R_b$.

### 2. MATCHING PAD

Conditions: $Z_1 > Z_2$, and $R_b = 0$

a. With straightedge, connect $Z_1$ on scale A to $Z_2$ on scale F. Read db loss on scale E.

b. Connect $Z_1$ on scale B to $Z_2$ on scale F. Read $\sqrt{Z_1 Z_2}$ on scale A.

c. Connect $\sqrt{Z_1 Z_2}$ on scale A to db loss on scale C. Read $R_c$ on scale F.

d. Connect $Z_1$ on scale A to db loss on scale D. Read $R_a + R_c$ on scale F.

e. Subtract $R_c$, leaving $R_a$.

### 3. MATCHING AND ATTENUATING PAD

Conditions: $Z_1 = Z_2$

a. With straightedge, connect $Z_1$ on scale F to $Z_2$ on scale B. Read $\sqrt{Z_1 Z_2}$ on scale A.

b. Connect $\sqrt{Z_1 Z_2}$ on scale A to required db loss on scale C. Read $R_c$ on scale F.

c. Connect $Z_1$ on scale A to db loss on scale D. Read $R_a + R_c$ on scale F.

d. Subtract $R_c$, leaving $R_a$.

e. Connect $Z_2$ on scale A to db loss on scale D. Read $R_c + R_c$ on scale F.

f. Subtract $R_c$, leaving $R_b$.

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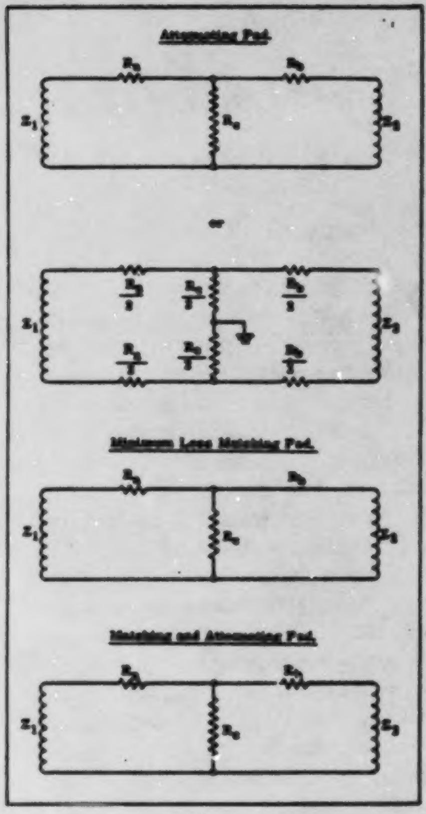

Figure 8. Pads

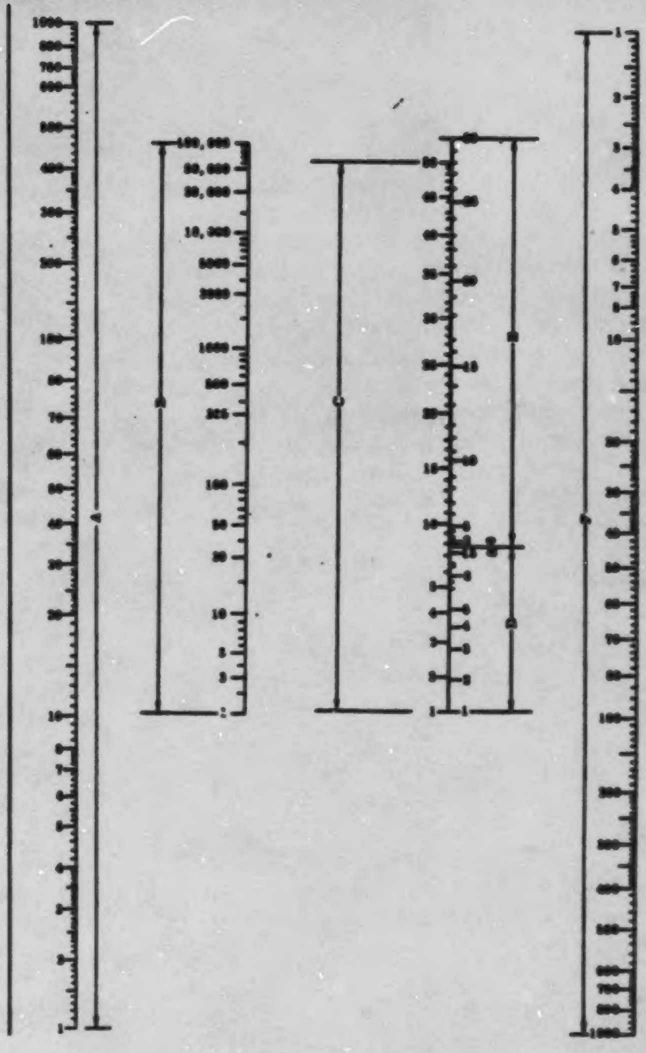

Figure 9. Nomograph for Determining Values of Network Matching and Attenuating Pads

THE DECIBEL

General

The db is the unit which has been widely adopted in radio, sound amplification, and other branches of electronics to express logarithmically the ratio between two power or voltage levels, and less commonly the ratio between two current levels. Although power, voltage, or current amplification, or the magnitude of a particular power, voltage, or current relative to a given reference value, can be expressed as an ordinary ratio, the db has been adopted because of its much greater convenience. Because the response of the human ear to sound waves is approximately proportional to the logarithm of the energy of the sound wave and is not proportional to the energy itself, the use of a logarithmic unit permits a closer approach to the reaction of the human ear. In other words, the impression gained by the human ear as to

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the magnitude of sound is roughly proportional to the logarithm of the actual energy contained in sound; hence the logarithmic unit provides a convenient method for comparison. Thus, e.g., a change in the gain of an amplifier, expressed in db, provides a much better index of the effect of the sound upon the ear than it does if expressed as a power or voltage ratio. The small numbers which may be used to indicate in db the gain or loss which correspond to large power, voltage, or current ratios, and the ease with which the db gains or losses may be added or subtracted are two additional important advantages in the use of the db.

### Power Ratio

The ratio, expressed in db, of two amounts of power, $P_2$ and $P_1$, is given by the following:

$$\text{db} = 10 \log_{10} \frac{P_2}{P_1}$$

The ratio, expressed in db, of two voltages, $E_2$ and $E_1$, or two currents, $I_2$ and $I_1$, is given by

$$\text{db} = 20 \log_{10} \frac{E_2}{E_1}, \text{ or db} = 20 \log_{10} \frac{I_2}{I_1}$$

The db is based upon power ratios; hence the preceding formula for deriving db equivalents from voltage or current ratios is TRUE ONLY IF THE IMPEDANCE IS THE SAME FOR BOTH VALUES OF VOLTAGE OR CURRENT: For example, if the above formulas were used, it would not be possible to obtain correct information on the gain of a given amplifier if the input impedance differed from that of the output. Hence, in circuits where the impedances differ, the expressions for db equivalents of voltage and current ratios become:

$$\text{db} = 20 \log_{10} \frac{E_2\sqrt{R_1}}{E_1\sqrt{R_2}}$$

and

$$\text{db} = 20 \log_{10} \frac{I_2\sqrt{R_2}}{I_1\sqrt{R_1}}$$

### Graphic Presentation

The graph (Figure 10) gives the values, expressed in db, which correspond to power, voltage, and current ratios from 1 to 100,000 and will be found of considerable assistance in quickly determining the db equivalent for a given ratio. It has been stressed that the db always refers to the ratio of two levels of power, voltage, or current. It is very often desirable, however, to express a single level or quantity of power, voltage, or current in db, as for example in transmission-line work, or in connection with the input or output of an amplifier. The db may be used as such an absolute unit by agreeing to specify the ratio always with respect to a fixed reference value, called the "zero level", and to indicate the absolute unit by its number of db above or below the fixed reference value. As an example, assume that it is desired to specify the value in db of the output from a 20-watt amplifier. Further assume that 0.001 watt is the reference level. This is equivalent to a power ratio of

$$\frac{20}{0.001}$$

or 20,000, which from the accompanying table, is found to be approximately 43 db; or, using the formula,

$$\text{db} = 10 \log_{10} \frac{20}{0.001} = 10 \times 4.3 = 43 \text{ db}$$

A "zero level" of 1 milliwatt (db above or below this level is commonly termed ±dbm) has gained considerable acceptance as the reference value, although 6 milliwatts and other values are also widely used. It is, therefore, very important, when the db is being used as an absolute unit in this way, that the reference value employed be clearly understood.

**Test Meters**

Many combination test instruments, particularly volt-ohm-milli-ammeters of the better type, are equipped with scales calibrated in db. Such meters are of great value in making many types of measurements where direct indication in db is desirable. When improperly used, however, the indication obtained may be so inaccurate as to be utterly meaningless. In most cases the calibration of these instruments is based upon an impedance of 600 ohms and a zero level of 1 milliwatt. THEREFORE, WHEN THE METER IS CONNECTED ACROSS AN IMPEDANCE HAVING A VALUE DIFFERENT FROM 600 OHMS, THE CALIBRATION WILL NOT BE CORRECT. The correction factor which must be applied is determined as follows:

$$\text{correction factor (db)} = 10 \log_{10} \frac{\text{Meter Z}}{\text{Circuit Z}}$$

When the impedance of the circuit under measurement is greater than the meter impedance, the correction factor is subtracted from the meter indication; when the value of the impedance is less than the meter impedance, the correction factor is added to the meter indication.

## MODULATION

### 1. AMPLITUDE MODULATION:

a. Percentage Modulation:

$$\%M = \frac{A}{R} \times 100$$

where %M = amount of modulation

A = peak amplitude of the audiomodulating signal

R = *RF* peak amplitude

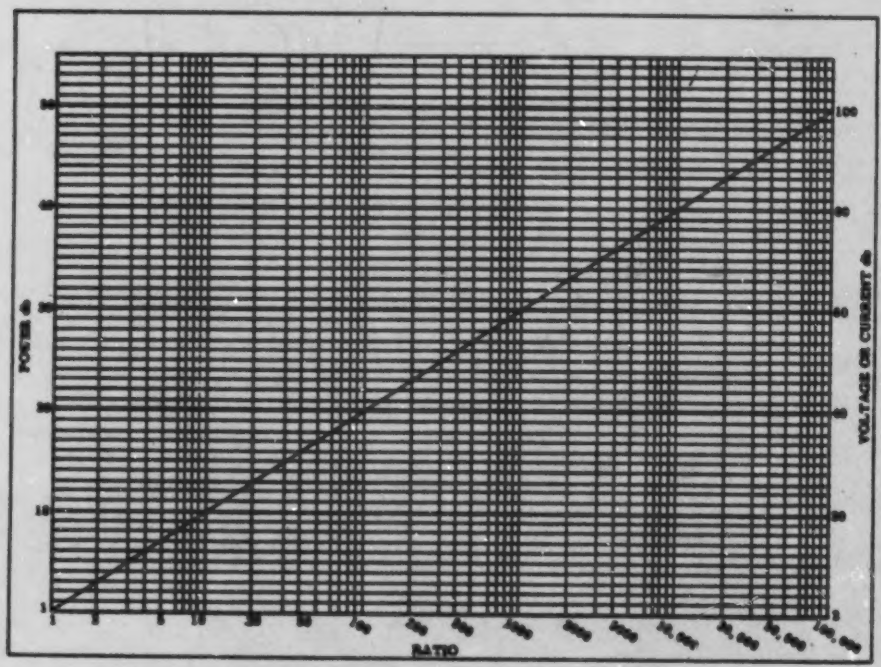


Figure 10. Decibels and Power, Voltage, or Current Ratios Graph

Percentage modulation may also be calculated from either of the following two formulas:

$$\%M = \frac{E_{max} - E_{min}}{2E_{av}} \times 100$$

$$\%M = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$$

where $E_{max}$ = maximum amplitude of modulated wave

$E_{min}$ = minimum amplitude of modulated wave

b. Power Calculations:

$$P_{dc} = E_b \times I_b$$

$$P_c = eff\ P_{dc}$$

$$P_{sb} = \frac{M^2}{2} \times P_c$$

$$P_t = P_c + P_{sb}$$

$$P_t = (1 + \frac{M^2}{2})P_c$$

$$P_{af} = \frac{M^2}{2} \times P_{dc}$$

$P_c$ = carrier power

$P_d$ = plate dissipation in watts

$P_t$ = total radiated power

$P_{af}$ = audio power from modulator

$P_{dc}$ = DC input power to *RF* stage

$P_{sb}$ = sideband power, including both sidebands

M = modulation factor (%M divided by 100)

eff = efficiency factor of *RF* stage (%eff divided by 100)

$I_b$ = plate current in amperes

$E_b$ = plate voltage in volts

## 2. FREQUENCY MODULATION

a. Modulation Percentage:

$$\%M = \frac{\text{frequency swing}}{\text{swing for } 100\%M} \times 100$$

b. Modulation Index:

$$MI = \frac{F_d}{F_a}$$

$F_d$ = frequency deviation

$F_a$ = audio frequency

c. Power:

$$P = E_b \times I_b \times F$$

P = operating power in watts

$E_b$ = plate voltage in volts

$I_b$ = plate current in amperes

F = efficiency factor

## ANTENNA FORMULAS

### 1. WAVELENGTH

a. Wavelength (meters):

$$\lambda = \frac{300,000}{f(\text{kHz})}$$

where f = frequency

b. Length of Half-Wave - Length (feet) of half-wave (radio wave) in space:

$$L = \frac{492}{f\ (\text{MHz})}$$

c. Length of half-wave up to 30 megahertz - Length (feet) of half-wave antenna, up to about 30 MHz (accurate for long-wire antennas):

$$L = \frac{492 \times 0.95}{f\ (\text{MHz})} = \frac{468}{f\ (\text{MHz})}$$

d. Length of half-wave up to 56 megahertz- Length (feet) of half-wave antenna:

$$L\ (\text{feet}) = \frac{492 \times 0.94}{f(\text{MHz})} = \frac{462}{f\ (\text{MHz})}$$

$$L\ (\text{inches}) = \frac{5,540}{f\ (\text{MHz})}$$

### 2. TRANSMISSION LINES:

a. Impedance of Parallel-Conductor Line:

$$Z = 276 \log \frac{D}{r}$$

D = spacing between conductors (inches)

r = radius of conductor (inches)

Log to base 10

b. Sending-End Impedance for a Half-Wave Transmission Line:

$$Z_a = Z_r$$

$Z_r$ = terminating or receiving-end impedance (ohms)

c. Impedance of coaxial or concentric line:

$$Z = 138 \log \frac{b}{a}$$

b = inside diameter of outer conductor (inches)

a = outside diameter of inner conductor (inches)

d. Length (feet) of quarter-wave transmission line:

$$L = \frac{246 \times Y}{f\ (\text{MHz})}$$

For parallel-wire line, Y = 0.975

For parallel-tubing line, Y = 0.95

For air-insulated concentric line, Y = 0.85

For rubber-insulated concentric line, Y = 0.56 to 0.65

### 3. FIELD STRENGTH CAN BE APPROXIMATED BY THIS FORMULA:

$$E = \frac{5,870\sqrt{P}}{D}$$

where E = field intensity in millivolts

P = transmitter power in watts

D = distance in miles

### 4. POWER IN TRANSMISSION LINE:

$$P = I^2 Z_o = E^2/Z_o$$

### 5. IMPEDANCE OF QUARTER-WAVE IMPEDANCE MATCHING:

$$Z_o = \sqrt{Z_1 Z_2}$$

where $Z_o$ = characteristic impedance of matching section

$Z_1$, $Z_2$ = impedances of lines to be matched, all measured in ohms

### 6. USEFUL CONVERSIONS AND FORMULAS IN WAVELENGTH TO FREQUENCY

a. $\lambda \text{ meters} = \frac{300}{F}$

b. $\lambda \text{ feet} = \frac{984}{F}$

F = frequency in megahertz

$\lambda$ = wavelength

### 7. EFFECTIVE AREA TO EFFECTIVE LENGTH:

$$A_e = (\ell_e)^2\left(\frac{377}{4R}\right)$$

where R = load resistance

$A_e$ = effective area of the antenna

$\ell_e$ = effective length of the antenna

For an antenna 50Ω impedance and matched to its load this becomes

$$A_e = 1.855(\ell_e)^2$$

in logs, $10 \log A_e = 20 \log \ell_e + 2.76$

### 8. ANTENNAS (IN-PHASE):

Relative field strength - $Et = 2I \operatorname{Cos}(a \operatorname{Sin} \theta)$

Directions of Maximums - $\theta = \operatorname{Sin}^{-1} \frac{(n \times 180°)}{a}$

Directions of the Nulls - $\theta = \operatorname{Sin}^{-1} \frac{(n \times 180° + 90°)}{a}$

### 9. ANTENNAS (OPPOSITELY PHASED):

Relative field strength - $\theta = 2I \operatorname{Sin}(a \operatorname{Sin}\theta)$

Direction of Nulls - $\theta = \operatorname{Sin}^{-1} \frac{(n \times 180°)}{a}$

Direction of Maximums - $\theta = \operatorname{Sin}^{-1} \frac{(n \times 180° + 90°)}{a}$

### 10. GLIDE SLOPE

Null antenna height - $H° = \frac{180}{\operatorname{Sin}\beta}$, $H' = \frac{H°}{121.7°}$

Reference antenna height - $h° = \frac{90}{\operatorname{Sin}\beta}$, $h' = \frac{h°}{121.7°}$

### 11. FIELD INTENSITY TO ANTENNA LOAD VOLTAGE:

$$\epsilon = \frac{E_r F_{MHz}}{\sqrt{g}} \times .0324$$

where $\epsilon$ = field intensity

$E_r$ = voltage at receiver input

g = antenna gain

| | Symbol | Practical Units | Definition |
|---|---|---|---|
| 1. Field intensity | E | $\mu$v/m<br>microvolts per meter | The measure of strength of electromagnetic radiation at a point in space. This is usually done at the location of a receiving antenna. |
| 2. Power density | $P_d$ | M W/M$^2$<br>milliwatts per square meter | This is the effective power of a radiated signal at a point in space. It is a function of the field intensity and the impedance of free space. |
| 3. Free space characteristic impedance | $Z_o$ | $\Omega$<br>ohms | The value of this impedance is approximately 377 $\Omega$. It is the result of the extension of the impedance theory to electromagnetic waves. |
| 4. Open circuit voltage induced in an antenna | $E_i$ | volts | The voltage measured with a high impedance device across the open terminals of an antenna. This is caused by the field intensity E. |
| 5. Effective area of an antenna | $A_e$ | meter$^2$ | A measure of the power transfer capabilities of an antenna $A_e = P_r/P_d$ |
| 6. Effective length of an antenna | $l_e$ | meters | A measure of the voltage transfer characteristic $l_e = \frac{E_i}{E}$ |
| 7. Power and voltage received at receiver load | $P_r$<br>$E_r$ | milliwatts<br>microvolts | Voltage induced and the power dissipated in the receiver input load by the field intensity present |

Figure 11. Field Intensity Measurement and Radio Frequency Interferency Definitions

Figure 11 (Contd)
Field Intensity Measurement and Radio Frequency Interferency Definitions.

| | | | | |
|---|---|---|---|---|
| 8. | Antenna gain (absolute) | g<br>G | numerical<br>db | This figure represents the ratio of the power radiated in a given direction from the antenna to that of an isotropic radiator radiating the same total power. This is the normal measure of antenna gain in field intensity equations. |
| 9. | Spectrum density | E<br>or<br>$P_{tr}$ | db above 1mv/mc or db above 1mw/mc | A power measure used to establish the power available in a transmitted signal which can be intercepted by various bandwidth receivers. By taking into account the bandwidth one can arrive at total received power. |
| 10. | a. Signal to noise ratio | S/N<br>20 log S/I | Volts/Volts<br>db | Normal measure of receiver merit: S = signal; N = internally generated noise. |
| | b. Signal to interference ratio | S/I<br>20 log S/I | Volts/Volts<br>db | Normal measure of the degree of interference: S = signal; I = interference. |
| | c. Interference to noise ratio | I/N<br>20 log I/N | Volts/Volts<br>db | Parameter for discerning the degree of interference. |
| 11. | RLOS | | | Radio line of sight. |
| 12. | ERP | | Watts | Effective power of a transmitter considering antenna gain, line losses, etc. |

### IN DECIBELS

$$\epsilon(\text{in db above 1 mv/m}) = E_r$$

$$= 10 \log g + 20 \log F_{MHz} - 29.79$$

dbm IN A 50Ω LOAD:

$$P_{dbm} = 20 \log E_r (\mu v) - 117$$

where $E_r$ (μx) = voltage across the load in microvolts

### 12. FIELD INTENSITY TO POWER INTENSITY:

$$(\text{db above 1 mv/m})$$

$$= P_d (\text{db above 1 mw/m}^2) + 116$$

where $\epsilon(\text{db above 1 mv/m}^2)$ = field intensity in db above one milliwatt per meter

$P_d(\text{db above 1 mw/m}^2)$ = power density in db above one milliwatt per meter

### 13. EFFECTIVE AREA TO GAIN IN DECIBELS:

$$A_e(\text{db}) = G\,(\text{db}) - 20 \log F_{MHz} + 38.6$$

where $A_e$(db) = effective area in db

G(db) = antenna gain in db

$A_e$ can be measured in db because by definition it is a power ratio

$$\left(A_e = \frac{P_I}{P_d}\right)$$

### 14. USEFUL CONVERSIONS AND FORMULAS IN FIELD INTENSITY MEASUREMENT, INTERFERENCE TO NOISE RATIO:

a. If (I/N) DB $>$ 0
then S/(N + I) db - I/N) db

b. If (I/N) db $<$ 0
then (S/N + I) db = (S/N) db

These equations state that if the db of a given interfering signal to the inherent noise level of a receiver is (a) greater than 0 then the resulting over-all signal to noise plus interference ratio is approximately the difference between the normal signal to noise ratio in db and the interference to noise ratio in db. In (2) if this ratio is less than 0 then it may be neglected.

### 15. PROPAGATION LOSS ALONG RLOS:

$$P_d = \frac{ERP}{4\pi R^2}$$

where RLOS = radio line of sight
ERP = effective radiated power
R = distance from transmitter

## COIL CALCULATIONS

### 1. SINGLE LAYER COILS

Single layer cylindrical coils, airwound or on nonmetallic cores, may be designed through he use of Nagaoka's formula:

$$L = k(\pi dT)^2/10^3 \ell$$

where L = inductance in microhenrys
d = diameter of coil in centimeters
ℓ = length of coil in centimeters
T = total number of turns
k = is a factor depending upon the ratio d/1

These calculations are for tightly wound coils, where the adjacent turns touch mechanically but are electrically insulated. If a spaced winding is used, a correction factor must be subtracted from the above. This factor is:

$$\Delta = 2\pi dn\,(A + B)\ell$$

where d = diameter of coil in centimeters n = number of turns per centimeter

$\ell$ = length in centimeters

A = diameter of bare wire/distance between center of turns

B = total number of turns in coil

2. COIL NOMOGRAPH - A single layer coil calculator nomograph is shown in Figure 12. Examples of using the nomograph are as follows:

a. Example Number 1:

Number of turns on coil = 100

Diameter of coil = 2 inches

Length of winding = 0.8 inches

$$K = \frac{\text{diameter}}{\text{length}} = \frac{2}{0.8} = 2.5$$

To find the inductance of the coil, proceed as follows:

(1) Connect 100 on N to 2.5 on K, and note the point where the line crosses the axis (3.8).

(2) Connect 3.8 on the axis to 2 on D.

(3) Read the inductance where this line crosses L (600 microhenrys).

b. Example Number 2:

Diameter of coil = 2.5 inches

Length of winding = 3 inches

$$K = \frac{\text{diameter}}{\text{length}} = \frac{2.5}{3} = 0.8$$

Inductance desired = 290 microhenrys.

To find the number of turns required, proceed as follows:

(1) Connect 290 on L to 2.5 on D, and note the point where the line crosses the axis (4.6).

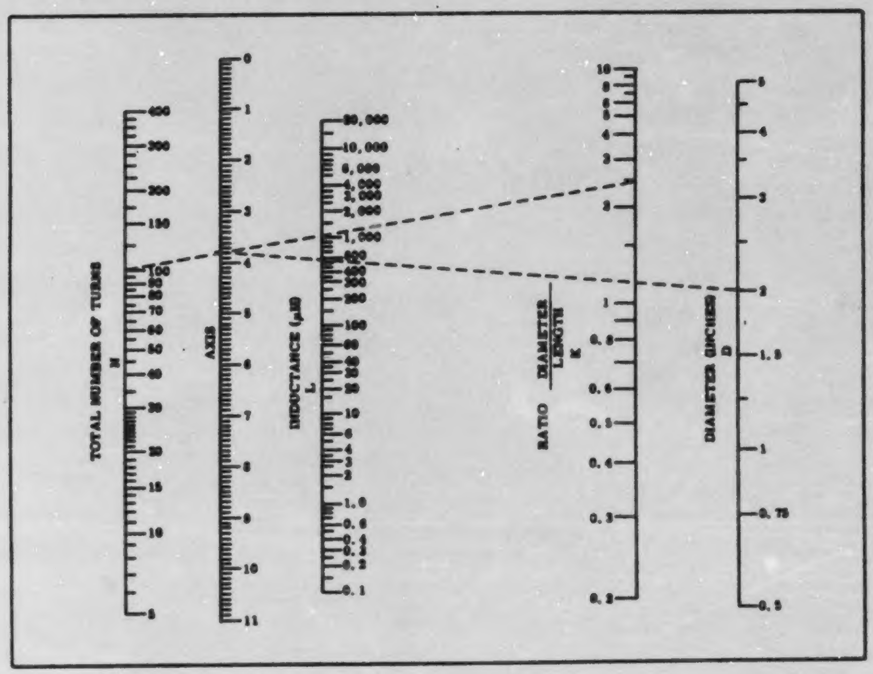


Figure 12. Single Layer Coil Calculator

(2) Connect 4.6 on the axis to 0.8 on K.

(3) Read the number of turns where the line crosses N (90 turns).

(4) From Figure 13 (Coil and Wire Data), it can be seen that this coil could be wound with No. 22 double-cotton-covered wire.

## POWER, ENERGY, AND THERMAL UNITS

1. **POWER IN ELECTRIC CIRCUITS** - Power is the rate of energy transfer. Its unit is the watt and may be expressed as:

$$P = E \times I,\ P = I^2R,\ \text{and}\ P = \frac{E^2}{R}$$

where E = volts

I = amperes

P = watts

In practice, the kilowatt and the horsepower are more convenient.

2. **ELECTRIC ENERGY** - Electric energy is equal to power x time. The practical unit of electrical energy is the kilowatt hour. The joule is another.

$$\text{watt-sec} = EIt$$

where watt-sec = joule

t = time in seconds

E = volts

I = amperes

kilowatt hour = $1000 \times (60)^2$ joule or watts-sec

3. THERMAL UNITS

a. Gram-Calorie - The amount of heat required to raise the temperature of one gram of water 1° Centigrade is the gram-calorie:

Centigrade interval =
9/5 Fahrenheit intervals

Fahrenheit interval =
5/9 Centigrade intervals

| GAGE (AWG (OR B & S) | NUMBER OF TURNS PER LINEAR INCH | | | | FEET PER POUND | FEET PER OHM |
|---|---|---|---|---|---|---|
| | ENAMEL | SSC | DSC SCC | DCC | | |
| 10 | 9.6 | | 9.3 | 8.9 | 31.43 | 1001 |
| 11 | 10.7 | | 10.3 | 9.8 | 40.12 | 794 |
| 12 | 12.0 | | 11.5 | 10.9 | 50.50 | 629.6 |
| 13 | 13.5 | | 12.8 | 12.0 | 63.80 | 499.3 |
| 14 | 15.0 | | 14.3 | 13.8 | 80.44 | 396.0 |
| 15 | 16.8 | | 15.8 | 14.7 | 101.4 | 314.0 |
| 16 | 18.9 | 18.9 | 17.9 | 16.4 | 127.9 | 249.0 |
| 17 | 21.2 | 21.2 | 19.9 | 18.1 | 161.3 | 197.5 |
| 18 | 23.6 | 23.6 | 22.0 | 19.8 | 203.4 | 156.5 |
| 19 | 26.4 | 26.4 | 24.4 | 21.8 | 256.5 | 124.2 |
| 20 | 29.4 | 29.4 | 27.0 | 23.6 | 323.4 | 98.5 |
| 21 | 33.1 | 32.7 | 29.8 | 26.0 | 407.8 | 78.11 |
| 22 | 37.0 | 36.5 | 34.1 | 28.0 | 514.2 | 62.96 |
| 23 | 41.3 | 40.6 | 37.6 | 31.6 | 648.4 | 49.13 |
| 24 | 46.3 | 45.3 | 41.5 | 35.6 | 817.7 | 38.96 |
| 25 | 51.7 | 50.4 | 45.6 | 38.6 | 1031 | 30.90 |
| 26 | 58.0 | 56.6 | 50.2 | 41.8 | 1300 | 24.50 |
| 27 | 64.9 | 61.5 | 55.0 | 45.0 | 1639 | 19.43 |
| 28 | 72.7 | 68.6 | 60.2 | 48.5 | 2067 | 15.41 |
| 29 | 81.6 | 74.8 | 65.4 | 51.8 | 2607 | 12.22 |
| 30 | 90.5 | 83.3 | 71.5 | 55.5 | 3287 | 9.691 |
| 31 | 101.0 | 92.0 | 77.5 | 59.2 | 4145 | 7.685 |
| 32 | 113 | 101 | 83.6 | 62.6 | 5227 | 6.095 |
| 33 | 127 | 110 | 90.3 | 66.3 | 6591 | 4.833 |
| 34 | 143 | 120 | 97.0 | 70.0 | 8310 | 3.833 |
| 35 | 158 | 133 | 104 | 73.5 | 10480 | 3.040 |
| 36 | 175 | 143 | 111 | 77.0 | 13210 | 2.411 |
| 37 | 198 | 154 | 118 | 80.3 | 16660 | 1.913 |
| 38 | 224 | 166 | 126 | 83.6 | 21010 | 1.516 |
| 39 | 248 | 181 | 133 | 86.6 | 26500 | 1.202 |
| 40 | 282 | 194 | 140 | 89.7 | 33410 | 0.9534 |

Figure 13. Coil and Wire Data

Temperature centigrade
= 5/9 x (temperature Fahrenheit - 32)

Temperature Fahrenheit
= (9/5 x temperature centigrade) +32

One gram-calorie
= 4.2 watt-seconds or joules

$$\text{calories} = \frac{1}{4.2} Pt$$

where

t = time in seconds

b. BTU - The relation between the electrical energy in a circuit and the heat in BTU:

$$H = 0.057\, I^2 Rt$$

where H = heat or BTU

I = amperes

t = time in minutes

## MAGNETIC LAWS

### General

The magnetic law relating to the parameters of magnetomotive force is a counterpart of Ohm's Law for electromotive forces. If E = IR in Ohm's Law, then $F = \phi R$ in the magnetic law, where electromotive force is analogous to magnetomotive force, F; electrical current is analogous to magnetic flux $\phi$; and electrical resistance is analogous to magnetic reluctance, R. The two laws are related since an emf is required to establish the mmf necessary to produce core flux. Several systems are in use for defining the magnetic parameters; however, the following definitions as to the irrational cgs electromagnetic units, are compared in Figures 14 and 15 with similar units used in other systems.

### Magnetomotive Force

Magnetomotive force relates magnetic potential to the product of ampere turns. It is force which produces lines of flux in a magnetic material.

$$F = .4\pi NI = R\phi = BAR = H\ell,$$

$$I = \frac{F}{.4\pi N}\text{, and } N = \frac{F}{.4\pi I}$$

### Magnetic Flux

Magnetic flux is equal to the total number of magnetic lines of force. Its dimensions are measured by lines or maxwells; 1 line = 1 maxwell. Flux in a magnetic circuit is proportional to ampere turns and inversely proportional to the reluctance of the magnetic path.

$$\phi = \frac{F}{R} = BA = \mu HA$$

### Flux Density

Flux density is measured in gauss and refers to the total amount of flux distributed over a given core area; 1 gauss = 1 maxwell/cm$^2$.

$$B = \frac{\phi}{A} = \frac{H\ell}{AR} = \mu HA$$

### Magnetizing Force

Magnetizing force is often referred to as field strength and magnetic intensity. With units of oersteds, it is a measure of the magnetic potential drop per unit core length. When a MMF of 1 gilbert is distributed across 1 cm of core length, the magnetic drop is 1 oersted.

$$H = \frac{F}{\ell} = \frac{.4\pi NI}{\ell} = \frac{B}{\mu} = \frac{BAR}{\ell} = \frac{\phi}{\mu A}$$

### Permeability

Permeability measures ease with which flux can pass through a magnetic material with reference to air. If the number of lines of flux in an air-core coil were increased by 5,000 when inserting a magnetic material into it, the permeability of the material would be 5,000. One oersted of magnetizing force will produce 1 gauss of flux density when the permeability is 1.

$$\mu = \frac{B}{H} = \frac{\mathcal{L}}{RA} = \frac{\phi}{HA} = \frac{\text{gauss}}{\text{oersteds}}$$

**Reluctance**

Reluctance is a measure of the opposition offered to lines of flux in the magnetic

| SYMBOL | DIMENSIONS | DEFINITION | USEFUL FORMULAS |
|---|---|---|---|
| $N$ | Turns | Turns through core | $N = \frac{Hl}{.4\pi I}$ |
| $I$ | Amperes | Average current | $I = \frac{Hl}{.4\pi N}$ |
| $NI$ | Ampere-Turns | Current times turns | $NI = \frac{Hl}{.4\pi}$ |
| $A$ | Square Centimeters | Effective core cross-section area | $A = \frac{\phi}{B} = \frac{l}{R\mu} = \frac{\phi}{\mu H}$ |
| $B$ | Gauss | Flux density | $B = \frac{\phi}{A}$ |
| $H$ | Oersteds | Magnetizing force | $H = \frac{.4\pi NI}{l}$ |
| $l$ | Centimeters | Mean magnetic path length | $l = \frac{.4\pi NI}{H} = \frac{BAR}{H}$ |
| $\mu$ | None | Permeability | $\mu = \frac{B}{H} = \frac{1}{v}$ |
| $\phi$ | Lines or Maxwells | Total flux | $\phi = BA$ |
| $F$ | Gilberts | Magneto-motive force | $F = .4\pi NI$ |
| $R$ | None | Reluctance | $R = \frac{l}{\mu A} = \frac{1}{P}$ |
| $P$ | None | Permeance | $P = \frac{\mu A}{l} = \frac{1}{R}$ |
| $v$ | None | Reluctivity | $v = \frac{1}{\mu}$ |

Figure 14. Magnetic Formulas and Symbols

| UNITS OF | TO CONVERT | INTO | MULTIPLY BY | CONVERSELY MULTIPLY BY |
|---|---|---|---|---|
| $\phi$ | Maxwells | Lines | 1 | 1 |
| $\phi$ | Maxwells | Webers | $10^{-8}$ | $10^{8}$ |
| $\phi$ | Webers | Volt-Seconds | .1 | 1 |
| $B$ | Maxwells/CM$^2$ | Gauss | 1 | 1 |
| $B$ | Lines/Inch$^2$ | Gauss | .1550 | 6.452 |
| $B$ | Webers/Meter$^2$ | Gauss | $10^{4}$ | $10^{-4}$ |
| $H$ | Gilberts/CM | Oersteds | 1 | 1 |
| $H$ | Ampere-Turns/Inch | Oersteds | .495 | 2.02 |
| $H$ | Ampere-Turns/Meter | Oersteds | .01257 | 79.58 |
| $H$ | Ampere-Turns/CM | Oersteds | 1.257 | .7958 |
| $H$ | Ampere-Turns/CM | Ampere-Turns/Inch | 2.540 | .3937 |
| $F$ | Ampere-Turns | Gilberts | 1.257 | .7958 |
| $\mu$ | Henrys/Meter | Gauss/Oersted | $7.958 \times 10^{5}$ | $1.257 \times 10^{-6}$ |
| $R$ | Ampere-Turn/Weber | Gilberts/Maxwell | $1.257 \times 10^{-8}$ | $7.958 \times 10^{7}$ |
| $P$ | Webers/Ampere-Turn | Maxwells/Gilbert | $7.958 \times 10^{7}$ | $1.257 \times 10^{-8}$ |

Figure 15. Magnetic Conversion Units

path of a core. Its value is dependent upon the physical dimensions and permeability of the core. The electrical counterpart of reluctance is resistance; however, reluctance has an additional characteristic in that it changes with permeability. Since permeability changes with flux density in most magnetic materials (certain powder cores bring exceptions), the inductance becomes conversely

$$\mathcal{R} = \frac{\ell}{\mu A} = \frac{\ell}{\left(\frac{B}{H}\right)A} = \frac{H\ell}{BA} = \frac{F}{\phi} = \frac{F}{BA} = \frac{1}{P} = \frac{\text{gilberts}}{\text{maxwells}}$$

### Permeance

The permeance of a magnetic material defines its ability to pass flux. Since permeance is the reciprocal of reluctance, any of the reluctance formulas may be used to find permeance by interchanging the denominator with the numerator.

### Reluctivity

This unit is the reciprocal of permeability. Any of the permeability formulas with the denominator and numerator inverted may be used to find reluctivity.

### Tractive Force of Magnetics

To calculate the "pull" of a magnet on a piece of steel, we use:

$$f = \frac{8.94B^2A}{10^8}$$

where $f$ = pull of magnetic, pounds

$B$ = flux density in airgap, gausses

$A$ = area of airgaps, square centimeters

## ARITHMETIC

Mathematics is a valuable tool. This is especially true of circuitry because the evaluation of an electronic circuit is largely a study of linear equations. An example is the linear relation of Ohm's Law:

$$E = IR$$

1. REAL NUMBERS - The real number system consists of zero; all whole numbers; all rational numbers; which can be expressed as whole numbers in fractional form; and all irrational numbers, which cannot be expressed as simple fractions.

2. POWERS OF TEN - Calculations often consist of unwieldy numbers and decimal fractions that can cause errors because of a misplaced decimal point, an accidental omission, or the addition of a cipher. By using the powers of 10 or exponents, a large number can be changed to another form which is easier to handle. In the powers of 10 system, a whole or mixed number is expressed as the product of a factor (usually less than 10) and the appropriate positive power of 10. To obtain the factor, move the decimal point the required number of places to the left. The value of the positive exponent of 10 is equal to the number of places the decimal point is moved. Thus, the number 300,000,000 can be written as $3 \times 10^8$. Similarly, a decimal fraction is expressed as the product of a factor and the appropriate negative power of 10. In this case, the decimal point is moved the required number of places to the right to obtain the factor, and the value of the negative exponent is equal to the number of places the decimal point is moved. Thus, 0.000,000,049 can be written as $4.9 \times 10^{-8}$, while 7,420,000,000 can be written as $7.42 \times 10^9$ (Figure 16).

a. EXAMPLES:

(1) 52,000 x 0.000000375 x 0.00004 x 155,000 x 60 reduced to powers of ten:

$5.2 \times 10^4 \times 3.75 \times 10^{-7} \times 4 \times 10^{-5} \times 1.55 \times 10^5 \times 60$

| | |
|---|---|
| $1 = 10^0$ | $1 = 10^0$ |
| $10 = 10^1$ | $0.1 = 10^{-1}$ |
| $100 = 10^2$ | $0.01 = 10^{-2}$ |
| $1000 = 10^3$ | $0.001 = 10^{-3}$ |
| $10,000 = 10^4$ | $0.0001 = 10^{-4}$ |
| $100,000 = 10^5$ | $0.00001 = 10^{-5}$ |
| $1,000,000 = 10^6$ | $0.000001 = 10^{-6}$ |

Figure 16. Exponents

In multiplication, add the exponents algebraically, thus:

$3.75 \times 4 \times 1.55 \times 60 \times 5.2 \times 10^{-3} = 7,254 \times 0.001$

Answer: = 7.254

(2) 0.0000014 x 0.000007 x 3.1416 x 150,000 x 0.00014 reduced to powers of ten:

$1.4 \times 10^{-6} \times 7 \times 10^{-6} \times 3.1416 \times 1.5 \times 10^5 \times 1.4 \times 10^{-4}$

Add the exponents algebraically, thus:

$1.4 \times 7 \times 3.1416 \times 1.5 \times 1.4 \times 10^{-11}$

Answer: = 0.0000000006464

$= 6.464 \times 10^{-10}$

$= 64.64 \times 10^{-11}$

$= 646.4 \times 10^{-12}$

b. FIVE SIMPLE RULES FOR HANDLING EXPONENTS:

(1) When multiplying numbers, add the exponents.

(2) When dividing numbers, subtract the exponents.

(3) When squaring a number, double its exponent .

(4) When obtaining a square root, halve the exponent.

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.0000 | 1.000000000 | 51 | 2,601 | 7.1414 | .019607843 |
| 2 | 4 | 1.4142 | .500000000 | 52 | 2,704 | 7.2111 | .019230769 |
| 3 | 9 | 1.7321 | .333333333 | 53 | 2,809 | 7.2801 | .018867925 |
| 4 | 16 | 2.0000 | .250000000 | 54 | 2,916 | 7.3485 | .018518519 |
| 5 | 25 | 2.2361 | .200000000 | 55 | 3,025 | 7.4162 | .018181818 |
| 6 | 36 | 2.4495 | .166666667 | 56 | 3,136 | 7.4833 | .017857143 |
| 7 | 49 | 2.6458 | .142857143 | 57 | 3,249 | 7.5498 | .017543860 |
| 8 | 64 | 2.8284 | .125000000 | 58 | 3,364 | 7.6158 | .017241379 |
| 9 | 81 | 3.0000 | .111111111 | 59 | 3,481 | 7.6811 | .016949153 |
| 10 | 100 | 3.1623 | .100000000 | 60 | 3,600 | 7.7460 | .016666667 |
| 11 | 121 | 3.3166 | .090909091 | 61 | 3,721 | 7.8102 | .016393443 |
| 12 | 144 | 3.4641 | .083333333 | 62 | 3,844 | 7.8740 | .016129032 |
| 13 | 169 | 3.6056 | .076923077 | 63 | 3,969 | 7.9373 | .015873016 |
| 14 | 196 | 3.7417 | .071428571 | 64 | 4,096 | 8.0000 | .015625000 |
| 15 | 225 | 3.8730 | .066666667 | 65 | 4,225 | 8.0623 | .015384615 |
| 16 | 256 | 4.0000 | .062500000 | 66 | 4,356 | 8.1240 | .015151515 |
| 17 | 289 | 4.1231 | .058823529 | 67 | 4,489 | 8.1854 | .014925373 |
| 18 | 324 | 4.2426 | .055555556 | 68 | 4,624 | 8.2462 | .014705882 |
| 19 | 361 | 4.3589 | .052631579 | 69 | 4,761 | 8.3066 | .014492754 |
| 20 | 400 | 4.4721 | .050000000 | 70 | 4,900 | 8.3666 | .014285714 |
| 21 | 441 | 4.5826 | .047619048 | 71 | 5,041 | 8.4261 | .014084507 |
| 22 | 484 | 4.6904 | .045454545 | 72 | 5,184 | 8.4853 | .013888889 |
| 23 | 529 | 4.7958 | .043478261 | 73 | 5,329 | 8.5440 | .013698630 |
| 24 | 576 | 4.8990 | .041666667 | 74 | 5,476 | 8.6023 | .013513514 |
| 25 | 625 | 5.0000 | .040000000 | 75 | 5,625 | 8.6603 | .013333333 |
| 26 | 676 | 5.0990 | .038461538 | 76 | 5,776 | 8.7178 | .013157895 |
| 27 | 729 | 5.1962 | .037037037 | 77 | 5,929 | 8.7750 | .012987013 |
| 28 | 784 | 5.2915 | .035714286 | 78 | 6,084 | 8.8318 | .012820513 |
| 29 | 841 | 5.3852 | .034482759 | 79 | 6,241 | 8.8882 | .012658228 |
| 30 | 900 | 5.4772 | .033333333 | 80 | 6,400 | 8.9443 | .012500000 |
| 31 | 961 | 5.5678 | .032258065 | 81 | 6,561 | 9.0000 | .012345679 |
| 32 | 1,024 | 5.6569 | .031250000 | 82 | 6,724 | 9.0554 | .012195122 |
| 33 | 1,089 | 5.7446 | .030303030 | 83 | 6,889 | 9.1104 | .012048193 |
| 34 | 1,156 | 5.8310 | .029411765 | 84 | 7,056 | 9.1652 | .011904762 |
| 35 | 1,225 | 5.9161 | .028571429 | 85 | 7,225 | 9.2195 | .011764706 |
| 36 | 1,296 | 6.0000 | .027777778 | 86 | 7,396 | 9.2736 | .011627907 |
| 37 | 1,369 | 6.0828 | .027027027 | 87 | 7,569 | 9.3274 | .011494253 |
| 38 | 1,444 | 6.1644 | .026315789 | 88 | 7,744 | 9.3808 | .011363636 |
| 39 | 1,521 | 6.2450 | .025641026 | 89 | 7,921 | 9.4340 | .011235955 |
| 40 | 1,600 | 6.3246 | .025000000 | 90 | 8,100 | 9.4868 | .011111111 |
| 41 | 1,681 | 6.4031 | .024390244 | 91 | 8,281 | 9.5394 | .010989011 |
| 42 | 1,764 | 6.4807 | .023809524 | 92 | 8,464 | 9.5917 | .010869565 |
| 43 | 1,849 | 6.5574 | .023255814 | 93 | 8,649 | 9.6437 | .010752688 |
| 44 | 1,936 | 6.6332 | .022727273 | 94 | 8,836 | 9.6954 | .010638298 |
| 45 | 2,025 | 6.7082 | .022222222 | 95 | 9,025 | 9.7468 | .010526316 |
| 46 | 2,116 | 6.7823 | .021739130 | 96 | 9,216 | 9.7980 | .010416667 |
| 47 | 2,209 | 6.8557 | .021276596 | 97 | 9,409 | 9.8489 | .010309278 |
| 48 | 2,304 | 6.9282 | .020833333 | 98 | 9,604 | 9.8995 | .010204082 |
| 49 | 2,401 | 7.0000 | .020408163 | 99 | 9,801 | 9.9499 | .010101010 |
| 50 | 2,500 | 7.0711 | .020000000 | 100 | 10,000 | 10.0000 | .010000000 |

Figure 17. Table of Squares and Square Roots.

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal |
|---|---|---|---|
| 101 | 10,201 | 10.0499 | .009900990 |
| 102 | 10,404 | 10.0995 | .009803922 |
| 103 | 10,609 | 10.1489 | .009708738 |
| 104 | 10,816 | 10.1980 | .009615385 |
| 105 | 11,025 | 10.2470 | .009523810 |
| 106 | 11,236 | 10.2956 | .009433962 |
| 107 | 11,449 | 10.3441 | .009345794 |
| 108 | 11,664 | 10.3923 | .009259259 |
| 109 | 11,881 | 10.4403 | .009174312 |
| 110 | 12,100 | 10.4881 | .009090909 |
| 111 | 12,321 | 10.5357 | .009009009 |
| 112 | 12,544 | 10.5830 | .008928571 |
| 113 | 12,769 | 10.6301 | .008849558 |
| 114 | 12,996 | 10.6771 | .008771930 |
| 115 | 13,225 | 10.7238 | .008695652 |
| 116 | 13,456 | 10.7703 | .008620690 |
| 117 | 13,689 | 10.8167 | .008547009 |
| 118 | 13,924 | 10.8628 | .008474576 |
| 119 | 14,161 | 10.9087 | .008403361 |
| 120 | 14,400 | 10.9545 | .008333333 |
| 121 | 14,641 | 11.0000 | .008264463 |
| 122 | 14,884 | 11.0454 | .008196721 |
| 123 | 15,129 | 11.0905 | .008130081 |
| 124 | 15,376 | 11.1355 | .008064516 |
| 125 | 15,625 | 11.1803 | .008000000 |
| 126 | 15,876 | 11.2250 | .007936508 |
| 127 | 16,129 | 11.2694 | .007874016 |
| 128 | 16,384 | 11.3137 | .007812500 |
| 129 | 16,641 | 11.3578 | .007751938 |
| 130 | 16,900 | 11.4018 | .007692308 |
| 131 | 17,161 | 11.4455 | .007633588 |
| 132 | 17,424 | 11.4891 | .007575758 |
| 133 | 17,689 | 11.5326 | .007518797 |
| 134 | 17,956 | 11.5758 | .007462687 |
| 135 | 18,225 | 11.6190 | .007407407 |
| 136 | 18,496 | 11.6619 | .007352941 |
| 137 | 18,769 | 11.7047 | .007299270 |
| 138 | 19,044 | 11.7473 | .007246377 |
| 139 | 19,321 | 11.7898 | .007194245 |
| 140 | 19,600 | 11.8322 | .007142857 |
| 141 | 19,881 | 11.8743 | .007092199 |
| 142 | 20,164 | 11.9164 | .007042254 |
| 143 | 20,449 | 11.9583 | .006993007 |
| 144 | 20,736 | 12.0000 | .006944444 |
| 145 | 21,025 | 12.0416 | .006896552 |
| 146 | 21,316 | 12.0830 | .006849315 |
| 147 | 21,609 | 12.1244 | .006802721 |
| 148 | 21,904 | 12.1655 | .006756757 |
| 149 | 22,201 | 12.2066 | .006711409 |
| 150 | 22,500 | 12.2474 | .006666667 |
| 151 | 22,801 | 12.2882 | .006622517 |
| 152 | 23,104 | 12.3288 | .006578947 |
| 153 | 23,409 | 12.3693 | .006535948 |
| 154 | 23,716 | 12.4097 | .006493506 |
| 155 | 24,025 | 12.4499 | .006451613 |
| 156 | 24,336 | 12.4900 | .006410256 |
| 157 | 24,649 | 12.5300 | .006369427 |
| 158 | 24,964 | 12.5698 | .006329114 |
| 159 | 25,281 | 12.6096 | .006289308 |
| 160 | 25,600 | 12.6491 | .006250000 |
| 161 | 25,921 | 12.6886 | .006211180 |
| 162 | 26,244 | 12.7279 | .006172840 |
| 163 | 26,569 | 12.7671 | .006134969 |
| 164 | 26,896 | 12.8062 | .006097561 |
| 165 | 27,225 | 12.8452 | .006060606 |
| 166 | 27,556 | 12.8841 | .006024096 |
| 167 | 27,889 | 12.9228 | .005988024 |
| 168 | 28,224 | 12.9615 | .005952381 |
| 169 | 28,561 | 13.0000 | .005917160 |
| 170 | 28,900 | 13.0384 | .005882353 |
| 171 | 29,241 | 13.0767 | .005847953 |
| 172 | 29,584 | 13.1149 | .005813953 |
| 173 | 29,929 | 13.1529 | .005780347 |
| 174 | 30,276 | 13.1909 | .005747126 |
| 175 | 30,625 | 13.2288 | .005714286 |
| 176 | 30,976 | 13.2665 | .005681818 |
| 177 | 31,329 | 13.3041 | .005649718 |
| 178 | 31,684 | 13.3417 | .005617978 |
| 179 | 32,041 | 13.3791 | .005586592 |
| 180 | 32,400 | 13.4164 | .005555556 |
| 181 | 32,761 | 13.4536 | .005524862 |
| 182 | 33,124 | 13.4907 | .005494505 |
| 183 | 33,489 | 13.5277 | .005464481 |
| 184 | 33,856 | 13.5647 | .005434783 |
| 185 | 34,225 | 13.6015 | .005405405 |
| 186 | 34,596 | 13.6382 | .005376344 |
| 187 | 34,969 | 13.6748 | .005347594 |
| 188 | 35,344 | 13.7113 | .005319149 |
| 189 | 35,721 | 13.7477 | .005291005 |
| 190 | 36,100 | 13.7840 | .005263158 |
| 191 | 36,481 | 13.8203 | .005235602 |
| 192 | 36,864 | 13.8564 | .005208333 |
| 193 | 37,249 | 13.8924 | .005181347 |
| 194 | 37,636 | 13.9284 | .005154639 |
| 195 | 38,025 | 13.9642 | .005128205 |
| 196 | 38,416 | 14.0000 | .005102041 |
| 197 | 38,809 | 14.0357 | .005076142 |
| 198 | 39,204 | 14.0712 | .005050505 |
| 199 | 39,601 | 14.1067 | .005025126 |
| 200 | 40,000 | 14.1421 | .005000000 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 201 | 40,401 | 14.1774 | .004975124 | 251 | 63,001 | 15.8430 | .003984064 |
| 202 | 40,804 | 14.2127 | .004950495 | 252 | 63,504 | 15.8745 | .003968254 |
| 203 | 41,209 | 14.2478 | .004926108 | 253 | 64,009 | 15.9060 | .003952569 |
| 204 | 41,616 | 14.2829 | .004901961 | 254 | 64,516 | 15.9374 | .003937008 |
| 205 | 42,025 | 14.3178 | .004878049 | 255 | 65,025 | 15.9687 | .003921569 |
| 206 | 42,436 | 14.3527 | .004854369 | 256 | 65,536 | 16.0000 | .003906250 |
| 207 | 42,849 | 14.3875 | .004830918 | 257 | 66,049 | 16.0312 | .003891051 |
| 208 | 43,264 | 14.4222 | .004807692 | 258 | 66,564 | 16.0624 | .003875969 |
| 209 | 43,681 | 14.4568 | .004784689 | 259 | 67,081 | 16.0935 | .003861004 |
| 210 | 44,100 | 14.4914 | .004761905 | 260 | 67,600 | 16.1245 | .003846154 |
| 211 | 44,521 | 14.5258 | .004739336 | 261 | 68,121 | 16.1555 | .003831418 |
| 212 | 44,944 | 14.5602 | .004716981 | 262 | 68,644 | 16.1864 | .003816794 |
| 213 | 45,369 | 14.5945 | .004694836 | 263 | 69,169 | 16.2173 | .003802281 |
| 214 | 45,796 | 14.6287 | .004672897 | 264 | 69,696 | 16.2481 | .003787879 |
| 215 | 46,225 | 14.6629 | .004651163 | 265 | 70,225 | 16.2788 | .003773585 |
| 216 | 46,656 | 14.6969 | .004629630 | 266 | 70,756 | 16.3095 | .003759398 |
| 217 | 47,089 | 14.7309 | .004608295 | 267 | 71,289 | 16.3401 | .003745318 |
| 218 | 47,524 | 14.7648 | .004587156 | 268 | 71,824 | 16.3707 | .003731343 |
| 219 | 47,961 | 14.7986 | .004566210 | 269 | 72,361 | 16.4012 | .003717472 |
| 220 | 48,400 | 14.8324 | .004545455 | 270 | 72,900 | 16.4317 | .003703704 |
| 221 | 48,841 | 14.8661 | .004524887 | 271 | 73,441 | 16.4621 | .003690037 |
| 222 | 49,284 | 14.8997 | .004504505 | 272 | 73,984 | 16.4924 | .003676471 |
| 223 | 49,729 | 14.9332 | .004484305 | 273 | 74,529 | 16.5227 | .003663004 |
| 224 | 50,176 | 14.9666 | .004464286 | 274 | 75,076 | 16.5529 | .003649635 |
| 225 | 50,625 | 15.0000 | .004444444 | 275 | 75,625 | 16.5831 | .003636364 |
| 226 | 51,076 | 15.0333 | .004424779 | 276 | 76,176 | 16.6132 | .003623188 |
| 227 | 51,529 | 15.0665 | .004405286 | 277 | 76,729 | 16.6433 | .003610108 |
| 228 | 51,984 | 15.0997 | .004385965 | 278 | 77,284 | 16.6733 | .003597122 |
| 229 | 52,441 | 15.1327 | .004366812 | 279 | 77,841 | 16.7033 | .003584229 |
| 230 | 52,900 | 15.1658 | .004347826 | 280 | 78,400 | 16.7332 | .003571429 |
| 231 | 53,361 | 15.1987 | .004329004 | 281 | 78,961 | 16.7631 | .003558719 |
| 232 | 53,824 | 15.2315 | .004310345 | 282 | 79,524 | 16.7929 | .003546099 |
| 233 | 54,289 | 15.2643 | .004291845 | 283 | 80,089 | 16.8226 | .003533569 |
| 234 | 54,756 | 15.2971 | .004273504 | 284 | 80,656 | 16.8523 | .003521127 |
| 235 | 55,225 | 15.3297 | .004255319 | 285 | 81,225 | 16.8819 | .003508772 |
| 236 | 55,696 | 15.3623 | .004237288 | 286 | 81,796 | 16.9115 | .003496503 |
| 237 | 56,169 | 15.3948 | .004219409 | 287 | 82,369 | 16.9411 | .003484321 |
| 238 | 56,644 | 15.4272 | .004201681 | 288 | 82,944 | 16.9706 | .003472222 |
| 239 | 57,121 | 15.4596 | .004184100 | 289 | 83,521 | 17,0000 | .003460208 |
| 240 | 57,600 | 15.4919 | .004166667 | 290 | 84,100 | 17.0294 | .003448276 |
| 241 | 58,081 | 15.5242 | .004149378 | 291 | 84,681 | 17.0587 | .003436426 |
| 242 | 58,564 | 15.5563 | .004132231 | 292 | 85,264 | 17.0880 | .003424658 |
| 243 | 59,049 | 15.5885 | .004115226 | 293 | 85,849 | 17.1172 | .003412969 |
| 244 | 59,536 | 15.6205 | .004098361 | 294 | 86,436 | 17.1464 | .003401361 |
| 245 | 60,025 | 15.6525 | .004081633 | 295 | 87,025 | 17.1756 | .003389831 |
| 246 | 60,516 | 15.6844 | .004065041 | 296 | 87,616 | 17.2047 | .003378378 |
| 247 | 61,009 | 15.7162 | .004048583 | 297 | 88,209 | 17.2337 | .003367003 |
| 248 | 61,504 | 15.7480 | .004032258 | 298 | 88,804 | 17.2627 | .003355705 |
| 249 | 62,001 | 15.7797 | .004016064 | 299 | 89,401 | 17.2916 | .003344482 |
| 250 | 62,500 | 15.8114 | .004000000 | 300 | 90,000 | 17.3205 | .003333333 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 301 | 90,601 | 17.3494 | .003322259 | 351 | 123,201 | 18.7350 | .002849003 |
| 302 | 91,204 | 17.3781 | .003311258 | 352 | 123,904 | 18.7617 | .002840909 |
| 303 | 91,809 | 17.4069 | .003300330 | 353 | 124,609 | 18.7883 | .002832861 |
| 304 | 92,416 | 17.4356 | .003289474 | 354 | 125,316 | 18.8149 | .002824859 |
| 305 | 93,025 | 17.4642 | .003278689 | 355 | 126,025 | 18.8414 | .002816901 |
| 306 | 93,636 | 17.4929 | .003267974 | 356 | 126,736 | 18.8680 | .002808989 |
| 307 | 94,249 | 17.5214 | .003257329 | 357 | 127,449 | 18.8944 | .002801120 |
| 308 | 94,864 | 17.5499 | .003246753 | 358 | 128,164 | 18.9209 | .002793296 |
| 309 | 95,481 | 17.5784 | .003236246 | 359 | 128,881 | 18.9473 | .002785515 |
| 310 | 96,100 | 17.6068 | .003225806 | 360 | 129,600 | 18.9737 | .002777778 |
| 311 | 96,721 | 17.6352 | .003215434 | 361 | 130,321 | 19.0000 | .002770083 |
| 312 | 97,344 | 17.6635 | .003205128 | 362 | 131,044 | 19.0263 | .002762431 |
| 313 | 97,969 | 17.6918 | .003194888 | 363 | 131,769 | 19.0526 | .002754821 |
| 314 | 98,596 | 17.7200 | .003184713 | 364 | 132,496 | 19.0788 | .002747253 |
| 315 | 99,225 | 17.7482 | .003174603 | 365 | 133,225 | 19.1050 | .002739726 |
| 316 | 99,856 | 17.7764 | .003164557 | 366 | 133,956 | 19.1311 | .002732240 |
| 317 | 100,489 | 17.8045 | .003154574 | 367 | 134,689 | 19.1572 | .002724796 |
| 318 | 101,124 | 17.8326 | .003144654 | 368 | 135,424 | 19.1833 | .002717391 |
| 319 | 101,761 | 17.8606 | .003134796 | 369 | 136,161 | 19.2094 | .002710027 |
| 320 | 102,400 | 17.8885 | .003125000 | 370 | 136,900 | 19.2354 | .002702703 |
| 321 | 103,041 | 17.9165 | .003115265 | 371 | 137,641 | 19.2614 | .002695418 |
| 322 | 103,684 | 17.9444 | .003105590 | 372 | 138,384 | 19.2873 | .002688172 |
| 323 | 104,329 | 17.9722 | .003095975 | 373 | 139,129 | 19.3132 | .002680965 |
| 324 | 104,976 | 18.0000 | .003086420 | 374 | 139,876 | 19.3391 | .002673797 |
| 325 | 105,625 | 18.0278 | .003076923 | 375 | 140,625 | 19.3649 | .002666667 |
| 326 | 106,276 | 18.0555 | .003067485 | 376 | 141,376 | 19.3907 | .002659574 |
| 327 | 106,929 | 18.0831 | .003058104 | 377 | 142,129 | 19.4165 | .002652520 |
| 328 | 107,584 | 18.1108 | .003048780 | 378 | 142,884 | 19.4422 | .002645503 |
| 329 | 108,241 | 18.1384 | .003039514 | 379 | 143,641 | 19.4679 | .002638522 |
| 330 | 108,900 | 18.1659 | .003030303 | 380 | 144,400 | 19.4936 | .002631579 |
| 331 | 109,561 | 18.1934 | .003021148 | 381 | 145,161 | 19.5192 | .002624672 |
| 332 | 110,224 | 18.2209 | .003012048 | 382 | 145,924 | 19.5448 | .002617801 |
| 333 | 110,889 | 18.2483 | .003003003 | 383 | 146,689 | 19.5704 | .002610966 |
| 334 | 111,556 | 18.2757 | .002994012 | 384 | 147,456 | 19.5959 | .002604167 |
| 335 | 112,225 | 18.3030 | .002985075 | 385 | 148,225 | 19.6214 | .002597403 |
| 336 | 112,896 | 18.3303 | .002976190 | 386 | 148,996 | 19.6469 | .002590674 |
| 337 | 113,569 | 18.3576 | .002967359 | 387 | 149,769 | 19.6723 | .002583979 |
| 338 | 114,244 | 18.3848 | .002958580 | 388 | 150,544 | 19.6977 | .002577320 |
| 339 | 114,921 | 18.4120 | .002949853 | 389 | 151,321 | 19.7231 | .002570694 |
| 340 | 115,600 | 18.4391 | .002941176 | 390 | 152,100 | 19.7484 | .002564103 |
| 341 | 116,281 | 18.4662 | .002932551 | 391 | 152,881 | 19.7737 | .002557545 |
| 342 | 116,964 | 18.4932 | .002923977 | 392 | 153,664 | 19.7990 | .002551020 |
| 343 | 117,649 | 18.5203 | .002915452 | 393 | 154,449 | 19.8242 | .002544529 |
| 344 | 118,336 | 18.5472 | .002906977 | 394 | 155,236 | 19.8494 | .002538071 |
| 345 | 119,025 | 18.5742 | .002898551 | 395 | 156,025 | 19.8746 | .002531646 |
| 346 | 119,716 | 18.6011 | .002890173 | 396 | 156,816 | 19.8997 | .002525253 |
| 347 | 120,409 | 18.6279 | .002881844 | 397 | 157,609 | 19.9249 | .002518892 |
| 348 | 121,104 | 18.6548 | .002873563 | 398 | 158,404 | 19.9499 | .002512563 |
| 349 | 121,801 | 18.6815 | .002865330 | 399 | 159,201 | 19.9750 | .002506266 |
| 350 | 122,500 | 18.7083 | .002857143 | 400 | 160,000 | 20.0000 | .002500000 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 401 | 160,801 | 20.0250 | .002493766 | 451 | 203,401 | 21.2368 | .002217295 |
| 402 | 161,604 | 20.0499 | .002487562 | 452 | 204,304 | 21.2603 | .002212389 |
| 403 | 162,409 | 20.0749 | .002481390 | 453 | 205,209 | 21.2838 | .002207506 |
| 404 | 163,216 | 20.0998 | .002475248 | 454 | 206,116 | 21.3073 | .002202643 |
| 405 | 164,025 | 20.1246 | .002469136 | 455 | 207,025 | 21.3307 | .002197802 |
| 406 | 164,836 | 20.1494 | .002463054 | 456 | 207,936 | 21.3542 | .002192982 |
| 407 | 165,649 | 20.1742 | .002457002 | 457 | 208,849 | 21.3776 | .002188184 |
| 408 | 166,464 | 20.1990 | .002450980 | 458 | 209,764 | 21.4009 | .002183406 |
| 409 | 167,281 | 20.2237 | .002444988 | 459 | 210,681 | 21.4243 | .002178649 |
| 410 | 168,100 | 20.2485 | .002439024 | 460 | 211,600 | 21.4476 | .002173913 |
| 411 | 168,921 | 20.2731 | .002433090 | 461 | 212,521 | 21.4709 | .002169197 |
| 412 | 169,744 | 20.2978 | .002427184 | 462 | 213,444 | 21.4942 | .002164502 |
| 413 | 170,569 | 20.3224 | .002421308 | 463 | 214,369 | 21.5174 | .002159827 |
| 414 | 171,396 | 20.3470 | .002415459 | 464 | 215,296 | 21.5407 | .002155172 |
| 415 | 172,225 | 20.3715 | .002409639 | 465 | 216,225 | 21.5639 | .002150538 |
| 416 | 173,056 | 20.3961 | .002403846 | 466 | 217,156 | 21.5870 | .002145923 |
| 417 | 173,889 | 20.4206 | .002398082 | 467 | 218,089 | 21.6102 | .002141328 |
| 418 | 174,724 | 20.4450 | .002392344 | 468 | 219,024 | 21.6333 | .002136752 |
| 419 | 175,561 | 30.4695 | .002386635 | 469 | 219,961 | 21.6564 | .002132196 |
| 420 | 176,400 | 20.4939 | .002380952 | 470 | 220,900 | 21.6795 | 002127660 |
| 421 | 177,241 | 20.5183 | .002375297 | 471 | 221,841 | 21.7025 | .002123142 |
| 422 | 178,084 | 20.5426 | .002369668 | 472 | 222,784 | 21.7256 | .002118644 |
| 423 | 178,929 | 20.5670 | .002364066 | 473 | 223,729 | 21.7486 | .002114165 |
| 424 | 179,776 | 20.5913 | .002358491 | 474 | 224,676 | 21.7715 | .002109705 |
| 425 | 180,625 | 20.6155 | .002352941 | 475 | 225,625 | 21.7945 | .002105263 |
| 426 | 181,476 | 20.6398 | .002347418 | 476 | 226,576 | 21.8174 | .002100840 |
| 427 | 182,329 | 20.6640 | .002341920 | 477 | 227,529 | 21.8403 | .002096436 |
| 428 | 183,184 | 20.6882 | .002336449 | 478 | 228,484 | 21.8632 | .002092050 |
| 429 | 184,041 | 20.7123 | .002331002 | 479 | 229,441 | 21.8861 | .002087683 |
| 430 | 184,900 | 20.7364 | .002325581 | 480 | 230,400 | 21.9089 | .002083333 |
| 431 | 185,761 | 20.7605 | .002320186 | 481 | 231,361 | 21.9317 | .002079002 |
| 432 | 186,624 | 20.7846 | .002314815 | 482 | 232,324 | 21.9545 | .002074689 |
| 433 | 187,489 | 20.8087 | .002309469 | 483 | 233,289 | 21.9773 | .002070393 |
| 434 | 188,356 | 20.8327 | .002304147 | 484 | 234,256 | 22.0000 | .002066116 |
| 435 | 189,225 | 20.8567 | .002298851 | 485 | 235,225 | 22.0227 | .002061856 |
| 436 | 190,096 | 20.8806 | .002293578 | 486 | 236,196 | 22.0454 | .002057613 |
| 437 | 190,969 | 20.9045 | .002288330 | 487 | 237,169 | 22.0681 | .002053388 |
| 438 | 191,844 | 20.9284 | .002283105 | 488 | 238,144 | 22.0907 | .002049180 |
| 439 | 192,721 | 20.9523 | .002277904 | 489 | 239,121 | 22.1133 | .002044990 |
| 440 | 193,600 | 20.9762 | .002272727 | 490 | 240,100 | 22.1359 | .002040816 |
| 441 | 194,481 | 21.0000 | .002267574 | 491 | 241,081 | 22.1585 | .002036660 |
| 442 | 195,364 | 21.0238 | .002262443 | 492 | 242,064 | 22.1811 | .002032520 |
| 443 | 196,249 | 21.0476 | .002257336 | 493 | 243,049 | 22.2036 | .002028398 |
| 444 | 197,136 | 21.0713 | .002252252 | 494 | 244,036 | 22.2261 | .002024291 |
| 445 | 198,025 | 21.0950 | .002247191 | 495 | 245,025 | 22.2486 | .002020202 |
| 446 | 198,916 | 21.1187 | .002242152 | 496 | 246,016 | 22.2711 | .002016129 |
| 447 | 199,809 | 21.1424 | .002237136 | 497 | 247,009 | 22.2985 | .002012072 |
| 448 | 200,704 | 21.1660 | .002232143 | 498 | 248,004 | 22.3159 | .002008032 |
| 449 | 201,601 | 21.1896 | .002227171 | 499 | 249,001 | 22.3383 | .002004008 |
| 450 | 202,500 | 21.2132 | .002222222 | 500 | 250,000 | 22.3607 | .002000000 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 501 | 251,001 | 22.3830 | .001996008 | 551 | 303,601 | 23.4734 | .001814882 |
| 502 | 252,004 | 22.4054 | .001992032 | 552 | 304,704 | 23.4947 | .001811594 |
| 503 | 253,009 | 22.4277 | .001988072 | 553 | 305,809 | 23.5160 | .001808318 |
| 504 | 254,016 | 22.4499 | .001984127 | 554 | 306,916 | 23.5372 | .001805054 |
| 505 | 255,025 | 22.4722 | .001980198 | 555 | 308,025 | 23.5584 | .001801802 |
| 506 | 256,036 | 22.4944 | .001976285 | 556 | 309,136 | 23.5797 | .001798561 |
| 507 | 257,049 | 22.5167 | .001972387 | 557 | 310,249 | 23.6008 | .001795332 |
| 508 | 258,064 | 22.5389 | .001968504 | 558 | 311,364 | 23.6220 | .001792115 |
| 509 | 259,081 | 22.5610 | .001964637 | 559 | 312,481 | 23.6432 | .001788909 |
| 510 | 260,100 | 22.5832 | .001960784 | 560 | 313,600 | 23.6643 | .001785714 |
| 511 | 261,121 | 22.6053 | .001956947 | 561 | 314,721 | 23.6854 | .001782531 |
| 512 | 262,144 | 22.6274 | .001953125 | 562 | 315,844 | 23.7065 | .001779359 |
| 513 | 263,169 | 22.6495 | .001949318 | 563 | 316,969 | 23.7276 | .001776199 |
| 514 | 264,196 | 22.6716 | .001945525 | 564 | 318,096 | 23.7487 | .001773050 |
| 515 | 265,225 | 22.6936 | .001941748 | 565 | 319,225 | 23.7697 | .001769912 |
| 516 | 266,256 | 22.7156 | .001937984 | 566 | 320,356 | 23.7908 | .001766784 |
| 517 | 267,289 | 22.7376 | .001934236 | 567 | 321,489 | 23.8118 | .001763668 |
| 518 | 268,324 | 22.7596 | .001930502 | 568 | 322,624 | 23.8328 | .001760563 |
| 519 | 269,361 | 22.7816 | .001926782 | 569 | 323,761 | 23.8537 | .001757469 |
| 520 | 270,400 | 22.8035 | .001923077 | 570 | 324,900 | 23.8747 | .001754386 |
| 521 | 271,441 | 22.8254 | .001919386 | 571 | 326,041 | 23.8956 | .001751313 |
| 522 | 272,484 | 22.8473 | .001915709 | 572 | 327,184 | 23.9165 | .001748252 |
| 523 | 273,529 | 22.8692 | .001912046 | 573 | 328,329 | 23.9374 | .001745201 |
| 524 | 274,576 | 22.8910 | .001908397 | 574 | 329,476 | 23.9583 | .001742160 |
| 525 | 275,625 | 22.9129 | .001904762 | 575 | 330,625 | 23.9792 | .001739130 |
| 526 | 276,676 | 22.9347 | .001901141 | 576 | 331,776 | 24.0000 | .001736111 |
| 527 | 277,729 | 22.9565 | .001897533 | 577 | 332,929 | 24.0208 | .001733102 |
| 528 | 278,784 | 22.9783 | .001893939 | 578 | 334,084 | 24.0416 | .001730104 |
| 529 | 279,841 | 23.0000 | .001890359 | 579 | 335,241 | 24.0624 | .001727116 |
| 530 | 280,900 | 23.0217 | .001886792 | 580 | 336,400 | 24.0832 | .001724138 |
| 531 | 281,961 | 23.0434 | .001883239 | 581 | 337,561 | 24.1039 | .001721170 |
| 532 | 283,024 | 23.0651 | .001879699 | 582 | 338,724 | 24.1247 | .001718213 |
| 533 | 284,089 | 23.0868 | .001876173 | 583 | 339,889 | 24.1454 | .001715266 |
| 534 | 285,156 | 23.1084 | .001872659 | 584 | 341,056 | 24.1661 | .001712329 |
| 535 | 286,225 | 23.1301 | .001869159 | 585 | 342,225 | 24.1868 | .001709402 |
| 536 | 287,296 | 23.1517 | .001865672 | 586 | 343,396 | 24.2074 | .001706485 |
| 537 | 288,369 | 23.1733 | .001862197 | 587 | 344,569 | 24.2281 | .001703578 |
| 538 | 289,444 | 23.1948 | .001858736 | 588 | 345,744 | 24.2487 | .001700680 |
| 539 | 290,521 | 23.2164 | .001855288 | 589 | 346,921 | 24.2693 | .001697793 |
| 540 | 291,600 | 23.2379 | .001851852 | 590 | 348,100 | 24.2899 | .001694915 |
| 541 | 292,681 | 23.2594 | .001848429 | 591 | 349,281 | 24.3105 | .001692047 |
| 542 | 293,764 | 23.2809 | .001845018 | 592 | 350,464 | 24.3311 | .001689189 |
| 543 | 294,849 | 23.3024 | .001841621 | 593 | 351,649 | 24.3516 | .001686341 |
| 544 | 295,936 | 23.3238 | .001838235 | 594 | 352,836 | 24.3721 | .001683502 |
| 545 | 297,025 | 23.3452 | .001834862 | 595 | 354,025 | 24.3926 | .001680672 |
| 546 | 298,116 | 23.3666 | .001831502 | 596 | 355,216 | 24.4131 | .001677852 |
| 547 | 299,209 | 23.3880 | .001828154 | 597 | 356,409 | 24.4336 | .001675042 |
| 548 | 300,304 | 23.4094 | .001824818 | 598 | 357,604 | 24.4540 | .001672241 |
| 549 | 301,401 | 23.4307 | .001821494 | 599 | 358,801 | 24.4745 | .001669449 |
| 550 | 302,500 | 23.4521 | .001818182 | 600 | 360,000 | 24.4949 | .001666667 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 601 | 361,201 | 24.5153 | .001663894 | 651 | 423,801 | 25.5147 | .001536098 |
| 602 | 362,404 | 24.5357 | .001661130 | 652 | 425,104 | 25.5343 | .001533742 |
| 603 | 363,609 | 24.5561 | .001658375 | 653 | 426,409 | 25.5539 | .001531394 |
| 604 | 364,816 | 24.5764 | .001655629 | 654 | 427,716 | 25.5734 | .001529052 |
| 605 | 366,025 | 24.5967 | .001652893 | 655 | 429,025 | 25.5930 | .001526718 |
| 606 | 367,236 | 24.6171 | .001650165 | 656 | 430,336 | 25.6125 | .001524390 |
| 607 | 368,449 | 24.6374 | .001647446 | 657 | 431,649 | 25.6320 | .001522070 |
| 608 | 369,664 | 24.6577 | .001644737 | 658 | 432,964 | 25.6515 | .001519757 |
| 609 | 370,881 | 24.6779 | .001642036 | 659 | 434,281 | 25.6710 | .001517451 |
| 610 | 372,100 | 24.6982 | .001639344 | 660 | 435,600 | 25.6905 | .001515152 |
| 611 | 373,321 | 24.7184 | .001636661 | 661 | 436,921 | 25.7099 | .001512859 |
| 612 | 374,544 | 24.7386 | .001633987 | 662 | 438,244 | 25.7294 | .001510574 |
| 613 | 375,769 | 24.7588 | .001631321 | 663 | 439,569 | 25.7488 | .001508296 |
| 614 | 376,996 | 24.7790 | .001628664 | 664 | 440,896 | 25.7682 | .001506024 |
| 615 | 378,225 | 24.7992 | .001626016 | 665 | 442,225 | 25.7876 | .001503759 |
| 616 | 379,456 | 24.8193 | .001623377 | 666 | 443,556 | 25.8070 | .001501502 |
| 617 | 380,689 | 24.8395 | .001620746 | 667 | 444,889 | 25.8263 | .001499250 |
| 618 | 381,924 | 24.8596 | .001618123 | 668 | 446,224 | 25.8457 | .001497006 |
| 619 | 383,161 | 24.8797 | .001615509 | 669 | 447,561 | 25.8650 | .001494768 |
| 620 | 384,400 | 24.8998 | .001612903 | 670 | 448,900 | 25.8844 | .001492537 |
| 621 | 385,641 | 24.9199 | .001610306 | 671 | 450,241 | 25.9037 | .001490313 |
| 622 | 386,884 | 24.9399 | .001607717 | 672 | 451,584 | 25.9230 | .001488095 |
| 623 | 388,129 | 24.9600 | .001605136 | 673 | 452,929 | 25.9422 | .001485884 |
| 624 | 389,376 | 24.9800 | .001602564 | 674 | 454,276 | 25.9615 | .001483680 |
| 625 | 390,625 | 25.0000 | .001600000 | 675 | 455,625 | 25.9808 | .001481481 |
| 626 | 391,876 | 25.0200 | .001597444 | 676 | 456,976 | 26.0000 | .001479290 |
| 627 | 393,129 | 25.0400 | .001594896 | 677 | 458,329 | 26.0192 | .001477105 |
| 628 | 394,384 | 25.0599 | .001592357 | 678 | 459,684 | 26.0384 | .001474926 |
| 629 | 395,641 | 25.0799 | .001589825 | 679 | 461,041 | 26.0576 | .001472754 |
| 630 | 396,900 | 25.0998 | .001587302 | 680 | 462,400 | 26.0768 | .001470588 |
| 631 | 398,161 | 25.1197 | .001584786 | 681 | 463,761 | 26.0960 | .001468429 |
| 632 | 399,424 | 25.1396 | .001582278 | 682 | 465,124 | 26.1151 | .001466276 |
| 633 | 400,689 | 25.1595 | .001579779 | 683 | 466,489 | 26.1343 | .001464129 |
| 634 | 401,956 | 25.1794 | .001577287 | 684 | 467,856 | 26.1534 | .001461988 |
| 635 | 403,225 | 25.1992 | .001574803 | 685 | 469,225 | 26.1725 | .001459854 |
| 636 | 404,496 | 25.2190 | .001572327 | 686 | 470,596 | 26.1916 | .001457726 |
| 637 | 405,769 | 25.2389 | .001569859 | 687 | 471,969 | 26.2107 | .001455604 |
| 638 | 407,044 | 25.2587 | .001567398 | 688 | 473,344 | 26.2298 | .001453488 |
| 639 | 408,321 | 25.2784 | .001564945 | 689 | 474,721 | 26.2488 | .001451379 |
| 640 | 409,600 | 25.2982 | .001562500 | 690 | 476,100 | 26.2679 | .001449275 |
| 641 | 410,881 | 25.3180 | .001560062 | 691 | 477,481 | 26.2869 | .001447178 |
| 642 | 412,164 | 25.3377 | .001557632 | 692 | 478,864 | 26.3059 | .001445087 |
| 643 | 413,449 | 25.3574 | .001555210 | 693 | 480,249 | 26.3249 | .001443001 |
| 644 | 414,736 | 25.3772 | .001552795 | 694 | 481,636 | 26.3439 | .001440922 |
| 645 | 416,025 | 25.3969 | .001550388 | 695 | 483,025 | 26.3629 | .001438849 |
| 646 | 417,316 | 25.4165 | .001547988 | 696 | 484,416 | 26.3818 | .001436782 |
| 647 | 418,609 | 25.4362 | .001545595 | 697 | 485,809 | 26.4008 | .001434720 |
| 648 | 419,904 | 25.4558 | .001543210 | 698 | 487,204 | 26.4197 | .001432665 |
| 649 | 421,201 | 25.4755 | .001540832 | 699 | 488,601 | 26.4386 | .001430615 |
| 650 | 422,500 | 25.4951 | .001538462 | 700 | 490,000 | 26.4575 | .001428571 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 701 | 491,401 | 26.4764 | .001426534 | 751 | 564,001 | 27.4044 | .001331558 |
| 702 | 492,804 | 26.4953 | .001424501 | 752 | 565,504 | 27.4226 | .001329787 |
| 703 | 494,209 | 26.5141 | .001422475 | 753 | 567,009 | 27.4408 | .001328021 |
| 704 | 495,616 | 26.5330 | .001420455 | 754 | 568,516 | 27.4591 | .001326260 |
| 705 | 497,025 | 26.5518 | .001418440 | 755 | 570,025 | 27.4773 | .001324503 |
| 706 | 498,436 | 26.5707 | .001416431 | 756 | 571,536 | 27.4955 | .001322751 |
| 707 | 499,849 | 26.5895 | .001414427 | 757 | 573,049 | 27.5136 | .001321004 |
| 708 | 501,264 | 26.6083 | .001412429 | 758 | 574,564 | 27.5318 | .001319261 |
| 709 | 502,681 | 26.6271 | .001410437 | 759 | 576,081 | 27.5500 | .001317523 |
| 710 | 504,100 | 26.6458 | .001408451 | 760 | 577,600 | 27.5681 | .001315789 |
| 711 | 505,521 | 26.6646 | .001406470 | 761 | 579,121 | 27.5862 | .001314060 |
| 712 | 506,944 | 26.6833 | .001404494 | 762 | 580,644 | 27.6043 | .001312336 |
| 713 | 508,369 | 26.7021 | .001402525 | 763 | 582,169 | 27.6225 | .001310616 |
| 714 | 509,796 | 26.7208 | .001400560 | 764 | 583,696 | 27.6405 | .001308901 |
| 715 | 511,225 | 26.7395 | .001398601 | 765 | 585,225 | 27.6586 | .001307190 |
| 716 | 512,656 | 26.7582 | .001396648 | 766 | 586,756 | 27.6767 | .001305483 |
| 717 | 514,089 | 26.7769 | .001394700 | 767 | 588,289 | 27.6948 | .001303781 |
| 718 | 515,524 | 26.7955 | .001392758 | 768 | 589,824 | 27.7128 | .001302083 |
| 719 | 516,961 | 26.8142 | .001390821 | 769 | 591,361 | 27.7308 | .001300390 |
| 720 | 518,400 | 26.8328 | .001388889 | 770 | 592,900 | 27.7489 | .001298701 |
| 721 | 519,841 | 26.8514 | .001386963 | 771 | 594,441 | 27.7669 | .001297017 |
| 722 | 521,284 | 26.8701 | .001385042 | 772 | 595,984 | 27.7849 | .001295337 |
| 723 | 522,729 | 26.8887 | .001383126 | 773 | 597,529 | 27.8029 | .001293661 |
| 724 | 524,176 | 26.9072 | .001381215 | 774 | 599,076 | 27.8209 | .001291990 |
| 725 | 525,625 | 26.9258 | .001379310 | 775 | 600,625 | 27.8388 | .001290323 |
| 726 | 527,076 | 26.9444 | .001377410 | 776 | 602,176 | 27.8568 | .001288660 |
| 727 | 528,529 | 26.9629 | .001375516 | 777 | 603,729 | 27.8747 | .001287001 |
| 728 | 529,984 | 26.9815 | .001373626 | 778 | 605,284 | 27.8927 | .001285347 |
| 729 | 531,441 | 27.0000 | .001371742 | 779 | 606,841 | 27.9106 | .001283697 |
| 730 | 532,900 | 27.0185 | .001369863 | 780 | 608,400 | 27.9285 | .001282051 |
| 731 | 534,361 | 27.0370 | .001367989 | 781 | 609,961 | 27.9464 | .001280410 |
| 732 | 535,824 | 27.0555 | .001366120 | 782 | 611,524 | 27.9643 | .001278772 |
| 733 | 537,289 | 27.0740 | .001364256 | 783 | 613,089 | 27.9821 | .001277139 |
| 734 | 538,756 | 27.0924 | .001362398 | 784 | 614,656 | 28.0000 | .001275510 |
| 735 | 540,225 | 27.1109 | .001360544 | 785 | 616,225 | 28.0179 | .001273885 |
| 736 | 541,696 | 27.1293 | .001358696 | 786 | 617,796 | 28.0357 | .001272265 |
| 737 | 543,169 | 27.1477 | .001356852 | 787 | 619,369 | 28.0535 | .001270648 |
| 738 | 544,644 | 27.1662 | .001355014 | 788 | 620,944 | 28.0713 | .001269036 |
| 739 | 546,121 | 27.1846 | .001353180 | 789 | 622,521 | 28.0891 | .001267427 |
| 740 | 547,600 | 27.2029 | .001351351 | 790 | 624,100 | 28.1069 | .001265823 |
| 741 | 549,081 | 27.2213 | .001349528 | 791 | 625,681 | 28.1247 | .001264223 |
| 742 | 550,564 | 27.2397 | .001347709 | 792 | 627,264 | 28.1425 | .001262626 |
| 743 | 552,049 | 27.2580 | .001345895 | 793 | 628,849 | 28.1603 | .001261034 |
| 744 | 553,536 | 27.2764 | .001344086 | 794 | 630,436 | 28.1780 | .001259446 |
| 745 | 555,025 | 27.2947 | .001342282 | 795 | 632,025 | 28.1957 | .001257862 |
| 746 | 556,516 | 27.3130 | .001340483 | 796 | 633,616 | 28.2135 | .001256281 |
| 747 | 558,009 | 27.3313 | .001338688 | 797 | 635,209 | 28.2312 | .001254705 |
| 748 | 559,504 | 27.3496 | .001336898 | 798 | 636,804 | 28.2489 | .001253133 |
| 749 | 561,001 | 27.3679 | .001335113 | 799 | 638,401 | 28.2666 | .001251564 |
| 750 | 562,500 | 27.3861 | .001333333 | 800 | 640,000 | 28.2843 | .001250000 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 801 | 641,601 | 28.3019 | .001248439 | 851 | 724,201 | 29.1719 | .001175088 |
| 802 | 643,204 | 28.3196 | .001246883 | 852 | 725,904 | 29.1890 | .001173709 |
| 803 | 644,809 | 28.3373 | .001245330 | 853 | 727,609 | 29.2062 | .001172333 |
| 804 | 646,416 | 28.3549 | .001243781 | 854 | 729,316 | 29.2233 | .001170960 |
| 805 | 648,025 | 28.3725 | .001242236 | 855 | 731,025 | 29.2404 | .001169591 |
| 806 | 649,636 | 28.3901 | .001240695 | 856 | 732,736 | 29.2575 | .001168224 |
| 807 | 651,249 | 28.4077 | .001239157 | 857 | 734,449 | 29.2746 | .001166861 |
| 808 | 652,864 | 28.4253 | .001237624 | 858 | 736,164 | 29.2916 | .001165501 |
| 809 | 654,481 | 28.4429 | .001236094 | 859 | 737,881 | 29.3087 | .001164144 |
| 810 | 656,100 | 28.4605 | .001234568 | 860 | 739,600 | 29.3258 | .001162791 |
| 811 | 657,721 | 28.4781 | .001233046 | 861 | 741,321 | 29.3428 | .001161440 |
| 812 | 659,344 | 28.4956 | .001231527 | 862 | 743;044 | 29.3598 | .001160093 |
| 813 | 660,969 | 28.5132 | .001230012 | 863 | 744,769 | 29.3769 | .001158749 |
| 814 | 662,596 | 28.5307 | .001228501 | 864 | 746,496 | 29.3939 | .001157407 |
| 815 | 664,225 | 28.5482 | .001226994 | 865 | 748,225 | 29.4109 | .001156069 |
| 816 | 665,856 | 28.5657 | .001225490 | 866 | 749,956 | 29.4279 | .001154734 |
| 817 | 667,489 | 28.5832 | .001223990 | 867 | 751,689 | 29.4449 | .001153403 |
| 818 | 669,124 | 28.6007 | .001222494 | 868 | 753,424 | 29.4618 | .001152074 |
| 819 | 670,761 | 28.6182 | .001221001 | 869 | 755,161 | 29.4788 | .001150748 |
| 820 | 672,400 | 28.6356 | .001219512 | 870 | 756,900 | 29.4958 | .001149425 |
| 821 | 674,041 | 28.6531 | .001218027 | 871 | 758,641 | 29.5127 | .001148106 |
| 822 | 675,684 | 28.6705 | .001216545 | 872 | 760,384 | 29.5296 | .001146789 |
| 823 | 677,329 | 28.6880 | .001215067 | 873 | 762,129 | 29.5466 | .001145475 |
| 824 | 678,976 | 28.7054 | .001213592 | 874 | 763,876 | 29.5635 | .001144165 |
| 825 | 680,625 | 28.7228 | .001212121 | 875 | 765,625 | 29.5804 | .001142857 |
| 826 | 682,276 | 28.7402 | .001210654 | 876 | 767,376 | 29.5973 | .001141553 |
| 827 | 683,929 | 28.7576 | .001209190 | 877 | 769,129 | 29.6142 | .001140251 |
| 828 | 685,584 | 28.7750 | .001207729 | 878 | 770,884 | 29.6311 | .001138952 |
| 829 | 687,241 | 28.7924 | .001206273 | 879 | 772,641 | 29.6479 | .001137656 |
| 830 | 688,900 | 28.8097 | .001204819 | 880 | 774,400 | 29.6648 | .001136364 |
| 831 | 690,561 | 28.8271 | .001203369 | 881 | 776,161 | 29.6816 | .001135074 |
| 832 | 692,224 | 28.8444 | .001201923 | 882 | 777,924 | 29.6985 | .001133787 |
| 833 | 693,889 | 28.8617 | .001200480 | 883 | 779,689 | 29.7153 | .001132503 |
| 834 | 695,556 | 28.8791 | .001199041 | 884 | 781,456 | 29.7321 | .001131222 |
| 835 | 697,225 | 28.8964 | .001197605 | 885 | 783,225 | 29.7489 | .001129944 |
| 836 | 698,896 | 28.9137 | .001196172 | 886 | 784,996 | 29.7658 | .001128668 |
| 837 | 700,569 | 28.9310 | .001194743 | 887 | 786,769 | 29.7825 | .001127396 |
| 838 | 702,244 | 28.9482 | .001193317 | 888 | 788,544 | 29.7993 | .001126126 |
| 839 | 703,921 | 28.9655 | .001191895 | 889 | 790,321 | 29.8161 | .001124859 |
| 840 | 705,600 | 28.9828 | .001190476 | 890 | 792,100 | 29.8329 | .001123596 |
| 841 | 707,281 | 29.0000 | .001189061 | 891 | 793,881 | 29.8496 | .001122334 |
| 842 | 708,964 | 29.0172 | .001187648 | 892 | 795,664 | 29.8664 | .001121076 |
| 843 | 710,649 | 29.0345 | .001186240 | 893 | 797,449 | 29.8831 | .001119821 |
| 844 | 712,336 | 29.0517 | .001184834 | 894 | 799,236 | 29.8998 | .001118568 |
| 845 | 714,025 | 29.0689 | .001183432 | 895 | 801,025 | 29.9166 | .001117318 |
| 846 | 715,716 | 29.0861 | .001182033 | 896 | 802,816 | 29.9333 | .001116071 |
| 847 | 717,409 | 29.1033 | .001180638 | 897 | 804,609 | 29.9500 | .001114827 |
| 848 | 719,104 | 29.1204 | .001179245 | 898 | 806,404 | 29.9666 | .001113586 |
| 849 | 720,801 | 29.1376 | .001177856 | 899 | 808,201 | 29.9833 | .001112347 |
| 850 | 722,500 | 29.1548 | .001176471 | 900 | 810,000 | 30.0000 | .001111111 |

Figure 17. Table of Squares and Square Roots (Contd)

| no. | square | sq. root | reciprocal | no. | square | sq. root | reciprocal |
|---|---|---|---|---|---|---|---|
| 901 | 811,801 | 30.0167 | .001109878 | 951 | 904,401 | 30.8383 | .001051525 |
| 902 | 813,604 | 30.0333 | .001108647 | 952 | 906,304 | 30.8545 | .001050420 |
| 903 | 815,409 | 30.0500 | .001107420 | 953 | 908,209 | 30.8707 | .001049318 |
| 904 | 817,216 | 30.0666 | .001106195 | 954 | 910,116 | 30.8869 | .001048218 |
| 905 | 819,025 | 30.0832 | .001104972 | 955 | 912,025 | 30.9031 | .001047120 |
| 906 | 820,836 | 30.0998 | .001103753 | 956 | 913,936 | 30.9192 | .001046025 |
| 907 | 822,649 | 30.1164 | .001102536 | 957 | 915,849 | 30.9354 | .001044932 |
| 908 | 824,464 | 30.1330 | .001101322 | 958 | 917,764 | 30.9516 | .001043841 |
| 909 | 826,281 | 30.1496 | .001100110 | 959 | 919,681 | 30.9677 | .001042753 |
| 910 | 828,100 | 30.1662 | .001098901 | 960 | 921,600 | 30.9839 | .001041667 |
| 911 | 829,921 | 30.1828 | .001097695 | 961 | 923,521 | 31.0000 | .001040583 |
| 912 | 831,744 | 30.1993 | .001096491 | 962 | 925,444 | 31.0161 | .001039501 |
| 913 | 833,569 | 30.2159 | .001095290 | 963 | 927,369 | 31.0322 | .001038422 |
| 914 | 835,396 | 30.2324 | .001094092 | 964 | 929,296 | 31.0483 | .001037344 |
| 915 | 837,225 | 30.2490 | .001092896 | 965 | 931,225 | 31.0644 | .001036269 |
| 916 | 839,056 | 30.2655 | .001091703 | 966 | 933,156 | 31.0805 | .001035197 |
| 917 | 840,889 | 30.2820 | .001090513 | 967 | 935,089 | 31.0966 | .001034126 |
| 918 | 842,724 | 30.2985 | .001089325 | 968 | 937,024 | 31.1127 | .001033058 |
| 919 | 844,561 | 30.3150 | .001088139 | 969 | 938,961 | 31.1288 | .001031992 |
| 920 | 846,400 | 30.3315 | .001086957 | 970 | 940,900 | 31.1448 | .001030928 |
| 921 | 848,241 | 30.3480 | .001085776 | 971 | 942,841 | 31.1609 | .001029866 |
| 922 | 850,084 | 30.3645 | .001084599 | 972 | 944,784 | 31.1769 | .001028807 |
| 923 | 851,929 | 30.3809 | .001083424 | 973 | 946,729 | 31.1929 | .001027749 |
| 924 | 853,776 | 30.3974 | .001082251 | 974 | 948,676 | 31.2090 | .001026694 |
| 925 | 855,625 | 30.4138 | .001081081 | 975 | 950,625 | 31.2250 | .001025641 |
| 926 | 857,476 | 30.4302 | .001079914 | 976 | 952,576 | 31.2410 | .001024590 |
| 927 | 859,329 | 30.4467 | .001078749 | 977 | 954,529 | 31.2570 | .001023541 |
| 928 | 861,184 | 30.4631 | .001077586 | 978 | 956,484 | 31.2730 | .001022495 |
| 929 | 863,041 | 30.4795 | .001076426 | 979 | 958,441 | 31.2890 | .001021450 |
| 930 | 864,900 | 30.4959 | .001075269 | 980 | 960,400 | 31.3050 | .001020408 |
| 931 | 866,761 | 30.5123 | .001074114 | 981 | 962,361 | 31.3209 | .001019368 |
| 932 | 868,624 | 30.5287 | .001072961 | 982 | 964,324 | 31.3369 | .001018330 |
| 933 | 870,489 | 30.5450 | .001071811 | 983 | 966,289 | 31.3528 | .001017294 |
| 934 | 872,356 | 30.5614 | .001070664 | 984 | 968,256 | 31.3688 | .001016260 |
| 935 | 874,225 | 30.5778 | .001069519 | 985 | 970,225 | 31.3847 | .001015228 |
| 936 | 876,096 | 30.5941 | .001068376 | 986 | 972,196 | 31.4006 | .001014199 |
| 937 | 877,969 | 30.6105 | .001067236 | 987 | 974,169 | 31.4166 | .001013171 |
| 938 | 879,844 | 30.6268 | .001066098 | 988 | 976,144 | 31.4325 | .001012146 |
| 939 | 881,721 | 30.6431 | .001064963 | 989 | 978,121 | 31.4484 | .001011122 |
| 940 | 883,600 | 30.6594 | .001063830 | 990 | 980,100 | 31.4643 | .001010101 |
| 941 | 885,481 | 30.6757 | .001062699 | 991 | 982,081 | 31.4802 | .001009082 |
| 942 | 887,364 | 30.6920 | .001061571 | 992 | 984,064 | 31.4960 | .001008065 |
| 943 | 889,249 | 30.7083 | .001060445 | 993 | 986,049 | 31.5119 | .001007049 |
| 944 | 891,136 | 30.7246 | .001059322 | 994 | 988,036 | 31.5278 | .001006036 |
| 945 | 893,025 | 30.7409 | .001058201 | 995 | 990,025 | 31.5436 | .001005025 |
| 946 | 894,916 | 30.7571 | .001057082 | 996 | 992,016 | 31.5595 | .001004016 |
| 947 | 896,809 | 30.7734 | .001055966 | 997 | 994,009 | 31.5753 | .001003009 |
| 948 | 898,704 | 30.7896 | .001054852 | 998 | 996,004 | 31.5911 | .001002004 |
| 949 | 900,601 | 30.8058 | .001053741 | 999 | 998,001 | 31.6070 | .001001001 |
| 950 | 902,500 | 30.8221 | .001052632 | 1000 | 1,000,000 | 31.6228 | .001000000 |

(5) When transferring a term with an exponent from the numerator to the denominator, or vice versa, change the sign of the exponent (or multiply the exponent by -1).

4. CALCULATION OF SQUARE ROOT - In calculating, or extracting, the square root of a number without a slide rule or a square-root table, separate operations are performed in a certain order. The method of finding the square root can best be explained by following each step of an actual sample.

a. STEP ONE - Suppose the square root of the whole number 31,505,769 is to be extracted. Beginning at the decimal point, moving to the left and ignoring the commas, divided the number into periods of two digits each:

```
31   50   57   69
```

Now find the largest single number of which the square is less than 31 (the first period). This is 5, since the square of 6 is greater than 31. Write the number 5 to the right of the number (as in long division) and also on the left:

```
5  √ 31   50   57   69  | 5
```

The square of this first digit, $5^2 = 25$, is written under the first period, 31, and subtracted from it, leaving a remainder of 6. The second period of the number is annexed to the remainder, giving 650 as the first dividend.

```
5  √ 31   50   57   69  | 5
     25
     
      6   50
```

b. STEP TWO - The first digit of the root (5) is now multiplied by 20, giving a product of 100, which is called the first trial divisor. Divide, the first dividend, 650, by 100 and the quotient of 6 is obtained. This is probably the second digit of the root. Write 6 in the root and also add to the first trial divisor, 100, giving a sum of 106, which is called the first complete divisor.

```
5  √ 31   50   57   69  | 56
     25

      6   50
```

c. STEP THREE - Multiply the first complete divisior, 106, by 6, the second digit of the root, obtaining the product of 636. Subtract this from the first dividend, 650, leaving a remainder of 14. Annexing the third period, 57, to this remainder leaves 1457 as the second dividend:

```
       5  √ 31   50   57   69  | 56
            25

    106)     6   50
             6   36

                 14   57
```

The two digits of the root, 56, are now multiplied by 20, giving 1120, which is the second trial divisor. Divide 1120 into the second dividend, 1457, which results in 1, which is the third digit of the root. Add 1 to the second trial divisor, 1120, giving 1121, as the second complete divisor. Multiply this divisor by the third digit of the root, 1, and subtract the product, 1121, from 1457, leaving a remainder of 336. Annex the fourth period, 69, to this remainder, 336, giving 33,669 as the third dividend.

```
       5  √ 31   50   57   69  | 561
            25

    106)     6   50
             6   36

   1121)         14   57
                 11   21

                  3   36   69
```

d. STEP FOUR - The three digits of the root, 561, are now multiplied by 20 giving a product of 11,220, which is the third trial divisor. Dividing 33,669 by the third trial divisor results in a quotient of 3, which is the fourth digit of the root. Adding 3 to 11,220 results in 11,223, the third complete divisor. Multiply 11,223 by 3, obtaining 33,669, which is subtracted from the third dividend, 33,669, leaving no remainder. This leaves the square root of 31,505,769 to be 5,613.

```
5       √31   50   57   69  | 5613
         25
106)      6   50
          6   36
1121)         14   57
              11   21
11223)         3   36   69
               3   36   69
```

## LOGARITHMS

1. DEFINITION - The logarithm of a quantity is the exponent of the power to which a given number, called the base, must be raised in order to equal the quantity. This exponential character of a logarithm is clearly shown in the following two examples:

a. $10^4 = 10{,}000$
$4 = \log$ of 10,000 to the base 10

b. $a^x = b$
$x = \log$ of b to the base a

2. PROPERTIES - Since a logarithm is an exponent, the properties of logarithms reflect the properties of exponents, as shown by the following theorems:

a. The logarithm of the product of two numbers is equal to the sum of the logarithms of the two numbers:

$$\log(a \times b) = \log a + \log b$$

b. The logarithm of the quotient of two numbers is equal to the logarithm of the numerator minus the logarithm of the denominator:

$$\log \frac{a}{b} = \log a - \log b$$

c. The logarithm of the power of a number is equal to the logarithm of the number multiplied by the exponent of the number:

$$\log a^x = x \log a$$

3. COMMON OR BRIGGS' SYSTEM OF LOGARITHMS - Many systems of logarithms are possible, since any number may be used as a base. However, the most common system in use is the Briggs' System, which employs 10 as the base. In this system, the logarithms of the integral powers of 10 are positive or negative whole numbers, as may be seen from the following lists:

| POWERS OF TEN | LOGARITHMIC NOTATION |
|---|---|
| $10^3 = 1000$ | $\log 1000 = 3$ |
| $10^2 = 100$ | $\log 100 = 2$ |
| $10^1 = 10$ | $\log 10 = 1$ |
| $10^0 = 1$ | $\log 1 = 0$ |
| $10^{-1} = 0.1$ | $\log 0.1 = -1$ |
| $10^{-2} = 0.01$ | $\log 0.01 = -2$ |
| $10^{-3} = 0.001$ | $\log 0.001 = -3$ |

The logarithm of a number which is not an integral power of 10 consists of a whole number plus a decimal; e.g., consider the logarithm of 465:

Since $10^2 < 465 < 10^3$

Then $2 < \log 465 < 3$

Or $\log 465 = 2 +$ (a decimal)

The integral part of a logarithm is called the characteristic, and the decimal part is called the mantissa.

4. DETERMINING THE LOGARITHM OF A NUMBER:

a. DETERMINING THE CHARACTERISTIC - There are two rules for determining the characteristic of a logarithm:

(1) If the given number is greater than one, its characteristic is one less than the number of digits to the left of the decimal point; e.g.,

6.3 has characteristic 0

63 has characteristic 1

630 has characteristic 2

6300 has characteristic 3

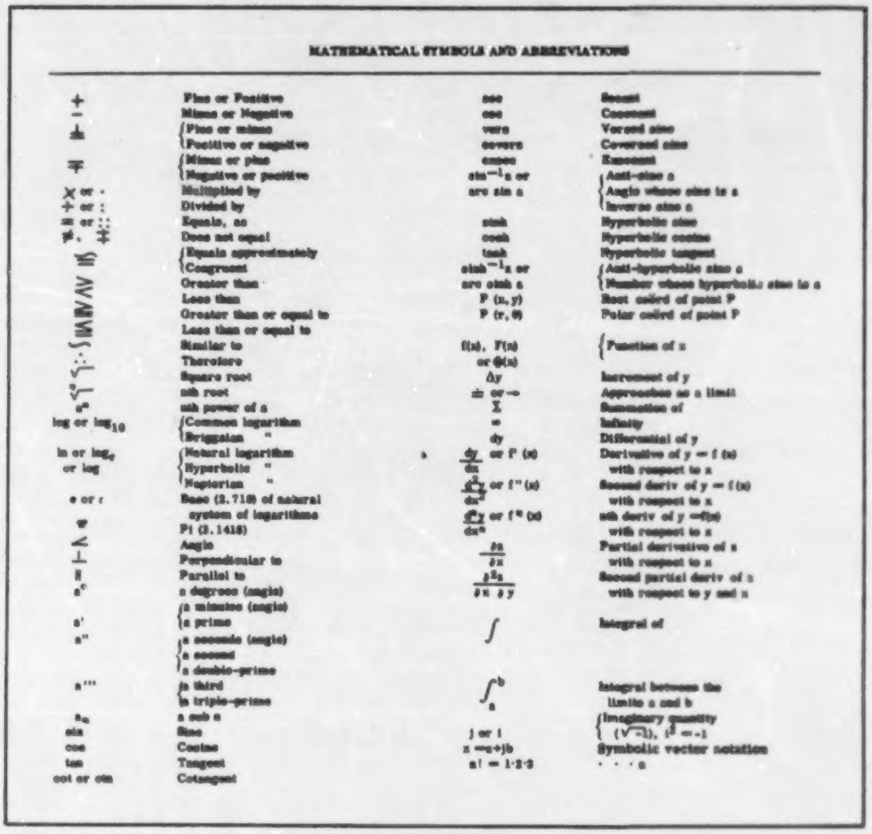
(2) If the given number is less than one, its characteristic is negative, and is one more than the number of zeros to the right of the decimal; e.g.,

0.81 has characteristic -1
(written as 9 - 10)

0.0813 has characteristic -2
(written as 8 - 10)

0.0082 has characteristic -3
(written as 7 - 10)

0.000802 has characteristic -4
(written as 6 - 10)



MATHEMATICAL SYMBOLS AND ABBREVIATIONS

| | | | |
|---|---|---|---|
| $+$ | Plus or Positive | sec | Secant |
| $-$ | Minus or Negative | csc | Cosecant |
| $\pm$ | {Plus or minus | vers | Versed sine |
| | Positive or negative | covers | Coversed sine |
| $\mp$ | {Minus or plus | exsec | Exsecant |
| | Negative or positive | $\sin^{-1}a$ or | {Anti-sine a |
| $\times$ or $\cdot$ | Multiplied by | arc sin a | Angle whose sine is a |
| $\div$ or $:$ | Divided by | | Inverse sine a |
| $=$ or $::$ | Equals, as | sinh | Hyperbolic sine |
| $\neq$ | Does not equal | cosh | Hyperbolic cosine |
| $\cong$ | {Equals approximately | tanh | Hyperbolic tangent |
| | Congruent | $\sinh^{-1}a$ or | {Anti-hyperbolic sine a |
| $>$ | Greater than | arc sinh a | Number whose hyperbolic sine is a |
| $<$ | Less than | $P(x, y)$ | Rect coord of point P |
| $\geqq$ | Greater than or equal to | $P(r, \theta)$ | Polar coord of point P |
| $\leqq$ | Less than or equal to | | |
| $\sim$ | Similar to | $f(x)$, $F(x)$ | {Function of x |
| $\therefore$ | Therefore | or $\phi(x)$ | |
| $\sqrt{\ }$ | Square root | $\Delta y$ | Increment of y |
| $\sqrt[n]{\ }$ | nth root | $\doteq$ or $\rightarrow$ | Approaches as a limit |
| $a^n$ | nth power of a | $\Sigma$ | Summation of |
| log or $\log_{10}$ | {Common logarithm | $\infty$ | Infinity |
| | Briggsian " | $dy$ | Differential of y |
| ln or $\log_\epsilon$ or log | {Natural logarithm | $\frac{dy}{dx}$ or $f'(x)$ | Derivative of $y = f(x)$ |
| | Hyperbolic " | | with respect to x |
| | Napierian " | $\frac{d^2y}{dx^2}$ or $f''(x)$ | Second deriv of $y = f(x)$ |
| e or $\epsilon$ | Base (2.718) of natural | | with respect to x |
| | system of logarithms | $\frac{d^ny}{dx^n}$ or $f^n(x)$ | nth deriv of $y = f(x)$ |
| $\pi$ | Pi (3.1416) | | with respect to x |
| $\angle$ | Angle | $\frac{\partial z}{\partial x}$ | Partial derivative of z |
| $\perp$ | Perpendicular to | | with respect to x |
| $\parallel$ | Parallel to | $\frac{\partial^2 z}{\partial x\ \partial y}$ | Second partial deriv of z |
| $a^\circ$ | a degrees (angle) | | with respect to y and x |
| | {a minutes (angle) | | |
| $a'$ | a prime | $\int$ | Integral of |
| $a''$ | {a seconds (angle) | | |
| | a second | | |
| | a double-prime | | |
| $a'''$ | {a third | $\int_a^b$ | Integral between the |
| | a triple-prime | | limits a and b |
| $a_n$ | a sub n | | {Imaginary quantity |
| sin | Sine | j or i | $(\sqrt{-1})$, $i^2 = -1$ |
| cos | Cosine | $x = a + jb$ | Symbolic vector notation |
| tan | Tangent | $n! = 1 \cdot 2 \cdot 3$ | $\cdots n$ |
| cot or ctn | Cotangent | | |

Figure 18. Mathematical Symbols and Abbreviations

|  | NUMERIC |  | RECIPROCAL |  |
|---|---|---|---|---|
|  | APPROX | MORE ACCURATELY | APPROX | MORE ACCURATELY |
| $\pi$ | 3.1416 | 3.141 593 | 0.318 3 | 0.318 309 9 |
| $2\pi$ | 6.2832 | 6.283 185 | 0.159 21 | 0.159 156 |
| $3\pi$ | 9.4248 | 9.424 778 | 0.106 1 | 0.106 103 |
| $4\pi$ | 12.566 | 12.566 371 | 0.0796 | 0.079 577 4 |
| $5\pi$ | 15.708 | 15.707 963 | 0.0637 | 0.063 662 |
| $\pi/2$ | 1.5708 | 1.570 796 | 0.6366 | 0.636 620 |
| $\pi/3$ | 1.0472 | 1.047 198 | 0.9549 | 0.954 930 |
| $\pi/4$ | 0.7854 | 0.785 398 | 1.273 | 1.273 23 |
| $\pi/6$ | 0.5236 | 0.523 599 | 1.910 | 1.909 86 |
| $\pi^2$ | 9.8696 | 9.869 604 | 0.1013 | 0.101 321 |
| $(2\pi)^2$ | 39.4784 | 39.478 414 | 0.0253 | 0.025 330 3 |
| $\pi^3$ | 31.0063 | 31.006 277 | 0.0323 | 0.032 252 |
| $\sqrt{\pi}$ | 1.7725 | 1.772 454 | 0.5642 | 0.564 190 |
| $\sqrt{\pi/2}$ | 1.2533 | 1.253 31 | 0.7979 | 0.797 887 |
| $\sqrt[3]{\pi}$ | 1.4646 | 1.464 592 | 0.6818 | 0.681 784 |
| $\log_{10}\pi$ | 0.4971 | 0.497 150 | 2.011 | 2.011 46 |
| $\log_{10}\pi/2$ | 0.1961 | 0.196 120 | 5.099 | 5.098 92 |
| $\log_{10}\pi^2$ | 0.9943 | 0.994 300 | 1.006 | 1.006 73 |
| $\log_{10}\sqrt{\pi}$ | 0.2486 | 0.248 575 | 4.023 | 4.022 93 |
| $\epsilon$ | 2.718 | 2.718 282 | 0.3679 | 0.367 879 |
| $\epsilon^2$ | 7.389 | 7.389 057 | 0.1353 | 0.135 335 |
| $\sqrt{\epsilon}$ | 1.649 | 1.648 721 | 0.6065 | 0.606 531 |
| $\log_{10}\epsilon$ | 0.4343 | 0.434 294 | 2.3026 | 2.302 585 |
| $\sqrt{2}$ | 1.414 | 1.4142 | 0.7071 | 0.707 113 5 |
| $\sqrt{3}$ | 1.732 | 1.7321 | 0.5773 | 0.577 334 2 |
| $\sqrt{5}$ | 2.236 | 2.2361 | 0.4472 | 0.447 296 |
| $\sqrt[3]{2}$ | 1.260 | 1.2599 | 0.7939 | 0.793 673 |
| $\sqrt[3]{3}$ | 1.442 | 1.4422 | 0.6933 | 0.693 386 |
| $\sqrt[3]{4}$ | 1.587 | 1.5874 | 0.6300 | 0.629 960 |
| $\sqrt[3]{5}$ | 1.710 | 1.7100 | 0.5848 | 0.584 79 |

Figure 19. Numerical Values for Various Constants

| N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0000000 | 0043214 | 0086002 | 0128372 | 0170333 | 0211893 | 0253059 | 0293838 | 0334238 | 0374265 |
| 11 | 0413927 | 0453230 | 0492180 | 0530784 | 0569049 | 0606978 | 0644580 | 0681859 | 0718820 | 0755470 |
| 12 | 0791812 | 0827854 | 0863598 | 0899051 | 0934217 | 0969100 | 1003705 | 1038037 | 1072100 | 1105897 |
| 13 | 1139434 | 1172713 | 1205739 | 1238516 | 1271048 | 1303338 | 1335389 | 1367206 | 1398791 | 1430148 |
| 14 | 1461280 | 1492191 | 1522883 | 1553360 | 1583625 | 1613680 | 1643529 | 1673173 | 1702617 | 1731863 |
| 15 | 1760913 | 1789769 | 1818436 | 1846914 | 1875207 | 1903317 | 1931246 | 1958997 | 1986571 | 2013971 |
| 16 | 2041200 | 2068259 | 2095150 | 2121876 | 2148438 | 2174839 | 2201081 | 2227165 | 2253093 | 2278867 |
| 17 | 2304489 | 2329961 | 2355284 | 2380461 | 2405492 | 2430380 | 2455127 | 2479733 | 2504200 | 2528530 |
| 18 | 2552725 | 2576786 | 2600714 | 2624511 | 2648178 | 2671717 | 2695129 | 2718416 | 2741578 | 2764618 |
| 19 | 2787536 | 2810334 | 2833012 | 2855573 | 2878017 | 2900346 | 2922561 | 2944662 | 2966652 | 2988531 |
| 20 | 3010300 | 3031961 | 3053514 | 3074960 | 3096302 | 3117539 | 3138672 | 3159703 | 3180633 | 3201463 |
| 21 | 3222193 | 3242825 | 3263359 | 3283796 | 3304138 | 3324385 | 3324538 | 3364597 | 3384565 | 3404441 |
| 22 | 3424227 | 3443923 | 3463530 | 3483049 | 3502480 | 3521825 | 3541084 | 3560259 | 3579348 | 3598355 |
| 23 | 3617278 | 3636120 | 3654880 | 3673559 | 3692159 | 3710679 | 3729120 | 3747483 | 3765770 | 3783979 |
| 24 | 3802112 | 3820170 | 3838154 | 3856063 | 3873898 | 3891661 | 3909351 | 3926970 | 3944517 | 3961993 |
| 25 | 3979400 | 3996737 | 4014005 | 4031205 | 4048337 | 4065402 | 4082400 | 4099331 | 4116197 | 4132998 |
| 26 | 4149733 | 4166405 | 4183013 | 4199557 | 4216039 | 4232459 | 4248816 | 4265113 | 4281348 | 4297523 |
| 27 | 4313638 | 4329693 | 4345689 | 4361626 | 4377506 | 4393327 | 4409091 | 4424798 | 4440448 | 4456042 |
| 28 | 4471580 | 4487063 | 4502491 | 4517864 | 4533183 | 4548449 | 4563660 | 4578819 | 4593925 | 4608978 |
| 29 | 4623980 | 4638930 | 4653829 | 4668676 | 4683473 | 4698220 | 4712917 | 4727564 | 4742163 | 4756712 |
| 30 | 4771213 | 4785665 | 4800069 | 4814426 | 4828736 | 4842998 | 4857214 | 4871384 | 4885507 | 4899585 |
| 31 | 4913617 | 4927604 | 4941546 | 4955443 | 4969296 | 4983106 | 4996871 | 5010593 | 5024271 | 5037907 |
| 32 | 5051500 | 5065050 | 5078559 | 5092025 | 5105450 | 5118834 | 5132176 | 5145478 | 5158738 | 5171959 |
| 33 | 5185139 | 5198280 | 5211381 | 5224442 | 5237465 | 5250448 | 5263393 | 5276299 | 5289167 | 5301997 |
| 34 | 5314789 | 5327544 | 5340261 | 5352941 | 5365584 | 5378191 | 5390761 | 5403295 | 5415792 | 5428234 |
| 35 | 5440680 | 5453071 | 5465427 | 5477747 | 5490033 | 5502284 | 5514500 | 5526682 | 5538830 | 5505944 |
| 36 | 5563025 | 5575072 | 5587086 | 5599066 | 5611014 | 5622929 | 5634811 | 5646661 | 5658478 | 5670264 |
| 37 | 5682017 | 5693739 | 5705429 | 5717088 | 5728716 | 5740313 | 5751878 | 5763414 | 5774918 | 5786392 |
| 38 | 5797836 | 5809250 | 5820634 | 5831988 | 5843312 | 5854607 | 5865873 | 5877110 | 5888317 | 5899496 |
| 39 | 5910646 | 5921768 | 5932861 | 5943926 | 5954962 | 5965971 | 5976952 | 5987905 | 5998831 | 6009729 |
| 40 | 6020600 | 6031444 | 3042261 | 6053050 | 6063814 | 6074550 | 6085260 | 6095944 | 6106602 | 6117233 |
| 41 | 6127839 | 6138418 | 6148972 | 6159501 | 6170003 | 6180481 | 6190933 | 6201361 | 6211763 | 6222140 |
| 42 | 6232493 | 6242821 | 6253125 | 6263404 | 6273659 | 6283889 | 6294096 | 6304279 | 6314438 | 6324573 |
| 43 | 6334685 | 6344773 | 6354837 | 6364879 | 6374897 | 6384893 | 6394865 | 6404814 | 6414741 | 6424645 |
| 44 | 6434527 | 6444386 | 6454223 | 6464037 | 6473830 | 6483600 | 6493349 | 6503075 | 6512780 | 6522463 |
| 45 | 6532125 | 6541765 | 6551384 | 6560982 | 6570559 | 6580114 | 6589648 | 6599162 | 6608655 | 6618127 |
| 46 | 6627578 | 6637009 | 6646420 | 6655810 | 6665180 | 6674530 | 6683859 | 6693169 | 6702459 | 6711728 |
| 47 | 6720979 | 6730209 | 6739420 | 6748611 | 6757783 | 6766936 | 6776070 | 6785184 | 6794279 | 6803355 |
| 48 | 6812412 | 6821451 | 6830470 | 6839471 | 6848454 | 6857417 | 6866363 | 6875290 | 6884198 | 6893089 |
| 49 | 6901961 | 6910815 | 6919651 | 6928469 | 6937269 | 6946052 | 6954817 | 6963564 | 6972293 | 6981005 |
| 50 | 6989700 | 6998377 | 7007037 | 7015680 | 7024305 | 7032914 | 7041505 | 7050080 | 7058637 | 7067178 |
| 51 | 7075702 | 7084209 | 7092700 | 7101174 | 7109631 | 7118072 | 7126497 | 7134905 | 7143298 | 7151674 |
| 52 | 7160033 | 7168377 | 7176705 | 7185017 | 7193313 | 7201593 | 7209857 | 7218106 | 7226339 | 7234557 |
| 53 | 7242759 | 7250945 | 7259116 | 7267272 | 7275413 | 7283538 | 7291648 | 7299743 | 7307823 | 7315888 |
| 54 | 7323938 | 7331973 | 7339993 | 7347998 | 7355989 | 7363965 | 7371926 | 7379873 | 7387806 | 7395723 |

Figure 20. Common Logarithms of Numbers

**Figure 20. Common Logarithms of Numbers (Contd)**

| N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 55 | 7403627 | 7411516 | 7419391 | 7427251 | 7435098 | 7442930 | 7450748 | 7458552 | 7466342 | 7474118 |
| 56 | 7481880 | 7489629 | 7497363 | 7505084 | 7512791 | 7520484 | 7528164 | 7535831 | 7543483 | 7551123 |
| 57 | 7558749 | 7566361 | 7573960 | 7581546 | 7589119 | 7596678 | 7604225 | 7611758 | 7619278 | 7626786 |
| 58 | 7634280 | 7641761 | 7649230 | 7656686 | 7664128 | 7671559 | 7678976 | 7686381 | 7693773 | 7701153 |
| 59 | 7708520 | 7715875 | 7723217 | 7730547 | 7737864 | 7745170 | 7752463 | 7759743 | 7767012 | 7774268 |
| 60 | 7781513 | 7788745 | 7795965 | 7803173 | 7810369 | 7817554 | 7824726 | 7831887 | 7839036 | 7846173 |
| 61 | 7853298 | 7860412 | 7867514 | 7874605 | 7881684 | 7888751 | 7895807 | 7902852 | 7909885 | 7916906 |
| 62 | 7923917 | 7930916 | 7937904 | 7944880 | 7951846 | 7958800 | 7965743 | 7972675 | 7979596 | 7986506 |
| 63 | 7993405 | 8000294 | 8007171 | 8014037 | 8020893 | 8027737 | 8034571 | 8041394 | 8048207 | 8055009 |
| 64 | 8061800 | 8068580 | 8075350 | 8082110 | 8088859 | 8095597 | 8102325 | 8109043 | 8115750 | 8122447 |
| 65 | 8129134 | 8135810 | 8142476 | 8149132 | 8155777 | 8162413 | 8169038 | 8175654 | 8182259 | 8188854 |
| 66 | 8195439 | 8202015 | 8208580 | 8215135 | 8221681 | 8228216 | 8234742 | 8241258 | 8247765 | 8254261 |
| 67 | 8260748 | 8267225 | 8273693 | 8280151 | 8286599 | 8293038 | 8299467 | 8305887 | 8312297 | 8318698 |
| 68 | 8325089 | 8331471 | 8337844 | 8344207 | 8350561 | 8356906 | 8363241 | 8369567 | 8375884 | 8382192 |
| 69 | 8388491 | 8394780 | 8401061 | 8407332 | 8413595 | 8419848 | 8426092 | 8432328 | 8438554 | 8444772 |
| 70 | 8450980 | 8457180 | 8463371 | 8469553 | 8475727 | 8481891 | 8488047 | 8494194 | 8500333 | 8506462 |
| 71 | 8512583 | 8518696 | 8524800 | 8530895 | 8536982 | 8543060 | 8549130 | 8555192 | 8561244 | 8567289 |
| 72 | 8573325 | 8579353 | 8585372 | 8591383 | 8597386 | 8603380 | 8609366 | 8615344 | 8621314 | 8627275 |
| 73 | 8633229 | 8639174 | 8645111 | 8651040 | 8656961 | 8662873 | 8668778 | 8674675 | 8680564 | 8686444 |
| 74 | 8692317 | 8698182 | 8704039 | 8709888 | 8715729 | 8721563 | 8727388 | 8733206 | 8739016 | 8744818 |
| 75 | 8750613 | 8756399 | 8762178 | 8767950 | 8773713 | 8779470 | 8785218 | 8790959 | 8796692 | 8802418 |
| 76 | 8808136 | 8813847 | 8819550 | 8825245 | 8830934 | 8836614 | 8842288 | 8847954 | 8853612 | 8859263 |
| 77 | 8864907 | 8870544 | 8876173 | 8881795 | 8887410 | 8893017 | 8898617 | 8904210 | 8909796 | 8915375 |
| 78 | 8920946 | 8926510 | 8932068 | 8937618 | 8943161 | 8948697 | 8954225 | 8959747 | 8965262 | 8970770 |
| 79 | 8976271 | 8981765 | 8987252 | 8992732 | 8998205 | 9003671 | 9009131 | 9014583 | 9020029 | 9025468 |
| 80 | 9030900 | 9036325 | 9041744 | 9047155 | 9052560 | 9057959 | 9063350 | 9068735 | 9074114 | 9079485 |
| 81 | 9084850 | 9090209 | 9095560 | 9100905 | 9106244 | 9111576 | 9116902 | 9122221 | 9127533 | 9132839 |
| 82 | 9138139 | 9143432 | 9148718 | 9153998 | 9159272 | 9164539 | 9169800 | 9175055 | 9180303 | 9185545 |
| 83 | 9190781 | 9196010 | 9201233 | 9206450 | 9211661 | 9216865 | 9222063 | 9227255 | 9232440 | 9237620 |
| 84 | 9242793 | 9247960 | 9253121 | 9258276 | 9263424 | 9268567 | 9273704 | 9278834 | 9283959 | 9289077 |
| 85 | 9294189 | 9299296 | 9304396 | 9309490 | 9314579 | 9319661 | 9324738 | 9329808 | 9334873 | 9339932 |
| 86 | 9344985 | 9350032 | 9355073 | 9360108 | 9365137 | 9370161 | 9375179 | 9380191 | 9385197 | 9390198 |
| 87 | 9395193 | 9400182 | 9405165 | 9410142 | 9415114 | 9420081 | 9425041 | 9429996 | 9434945 | 9439889 |
| 88 | 9444827 | 9449759 | 9454686 | 9459607 | 9464523 | 9469433 | 9474337 | 9479236 | 9484130 | 9489018 |
| 89 | 9493900 | 9498777 | 9503649 | 9508515 | 9513375 | 9518230 | 9523080 | 9527924 | 9532763 | 9537597 |
| 90 | 9542425 | 9547248 | 9552065 | 9556878 | 9561684 | 9566486 | 9571282 | 9576073 | 9580858 | 9585639 |
| 91 | 9590414 | 9595184 | 9599948 | 9604708 | 9609462 | 9614211 | 9618955 | 9623693 | 9628427 | 9633155 |
| 92 | 9637878 | 9642596 | 9647309 | 9652017 | 9656720 | 9661417 | 9666110 | 9670797 | 9675480 | 9680157 |
| 93 | 9684829 | 9689497 | 9694159 | 9698816 | 9703469 | 9708116 | 9712758 | 9717396 | 9722028 | 9726656 |
| 94 | 9731279 | 9735896 | 9740509 | 9745117 | 9749720 | 9754318 | 9758911 | 9763500 | 9768083 | 9772662 |
| 95 | 9777236 | 9781805 | 9786369 | 9790929 | 9795484 | 9800034 | 9804579 | 9809119 | 9813655 | 9818186 |
| 96 | 9822712 | 9827234 | 9831751 | 9836263 | 9840770 | 9845273 | 9849771 | 9854265 | 9858754 | 9863238 |
| 97 | 9867717 | 9872192 | 9876663 | 9881128 | 9885590 | 9890046 | 9894498 | 9898946 | 9903389 | 9907827 |
| 98 | 9912261 | 9916690 | 9921115 | 9925535 | 9929951 | 9934362 | 9938769 | 9943172 | 9947569 | 9951963 |
| 99 | 9956352 | 9960737 | 9965117 | 9969492 | 9973864 | 9978231 | 9982593 | 9986952 | 9991305 | 9995655 |

b. DETERMINING THE MANTISSA - Determining the mantissa requires the use of a table of logarithms. A table which gives the mantissa of seven significant figures for any three-digit number is contained in Figure 20, pages 139 and 140. The first two digits of the number are found in the left-hand column under N, and the third digit is found in the horizontal row of figures across the top of the table; e.g., to find the mantissa for 195, look under N for 19, and proceed horizontally across the table to column 5, which contains the desired mantissa. Thus the mantissa for 195 is 0.2900346, and the complete logarithm is 2.2900346 (characteristic is 3 minus 1).

c. GENERAL RULES - Numbers with the same sequence of digits always have the same mantissa, but the characteristics may be different depending on the position of the decimal point. A mantissa is always a positive quantity. A negative characteristic is written in terms of the proper positive number minus 10; e.g.;

$$\log 36.3 = 1.5587086$$

$$\log 0.0362 = 8.5587086 - 10$$

$$\log 0.00362 = 7.5587086 - 10$$

5. USE OF TABLE - The table may be used for two purposes:

a. TO FIND THE LOGARITHM OF A GIVEN NUMBER - Illustrated above.

b. TO FIND THE NUMBER, GIVEN THE LOGARITHM - The number is called the antilogarithm; e.g., the antilogarithm of 8.7109631 - 10 is found as follows: Locate the mantissa 0.7109631 in Figure 20. Find the number which corresponds to it, and place the decimal point in accordance with the second rule for determining characteristics. Thus the desired antilogarithm is:

$$\text{antilog } 8.7109631 - 10 = 0.0514$$
(characteristic is -2)

6. INTERPOLATION - To find the mantissa of a number having four or more digits requires the use of a process called interpolation. This process makes it possible to estimate the desired value from the two closest values that are given in the table. Interpolation is based on the asumption that for a small change in the number, there will be a corresponding small but proportional change in the mantissa. The principles of interpolation are explained in the following examples:

a. EXAMPLE 1 - Find the logarithm of 34.68:

Solution: First, write the characteristic 1. Since 34.68 lies between 34.60 and 34.70, the desired mantissa must lie between the mantissas for these 2 numbers. The mantissa is estimated as follows:

$$\begin{aligned}\text{Mantissa for } 3460 &= 0.5390761\\ \text{Mantissa for } 3470 &= \underline{0.5403295}\end{aligned}$$

$$\text{Difference} = 0.0012534$$

Difference between 3460 and 3470 = 10

Difference between 3460 and 3468 = 8

Hence, 8/10 of 0.0012534, or 0.00100272, must be added to 0.5390761. Therefore, the logarithm of 34.68 is 1.5400788. NOTE: All mantissas are kept to seven decimal places. If the eighth digit of the amount added is less than 0.5, the eighth digit is simply dropped. If it is 0.5 or greater, the seventh digit is increased by 1.

b. EXAMPLE 2 - Find the antilogarithm of 8.9968345 - 10.

Solution: Since this mantissa is not given in the table, the two closest values and their corresponding numbers are written with the given mantissa, as follows:

$$0.0004375\left\{\begin{matrix}\left.\begin{matrix}0.9965117\\ \\ 0.9968345\end{matrix}\right\}0.0003228\\ 0.9969492\end{matrix}\right. \qquad x\left\{\begin{matrix}992\\ \\ \underline{\qquad}\\ 993\end{matrix}\right\}1$$

The amount to be added to 992 is called X.

By proportion $\frac{X}{1} = \frac{0.0003228}{0.0004375}$ or

$$X = \frac{3228}{4375} \times 1 = \quad 738$$

Hence, the digits of the antilogarithm are 992738. Therefore, antilog 8.9968345 - 10 = 0.992738.

7. COLOGARITHMS - The cologarithm of a number is the logarithm of the reciprocal of the number.

$$\text{colog } N = \log \frac{1}{N} = \log 1 - \log N$$

As an example, the cologarithm of 18.6 may be found as follows:

$$\log 1 = 10.0000000 - 10$$

subtract $\quad \log 18.6 = \underline{\ 1.2695129\ }$

$$\text{colog } 18.6 = \ 8.7304871 - 10$$

Cologarithms may be used for computation in cases such as the following:

$$\log \frac{294}{6.3} = \log 294 - \log 6.3 = \log 294 + \text{colog } 6.3$$

8. NATURAL SYSTEM OF LOGARITHMS - All that has been said of the common system of logarithms holds true for any system of logarithms. In the natural system of logarithms, the number 2.71828 is used as a base. This is commonly referred to as epsilon ($\epsilon$). It is only necessary to remember that the natural logarithm of a number is 2.3026 times the common logarithm of that same number. Tables of natural logarithms have been included. The common logarithm of a number is 0.4343 times the natural logarithm of that same number. Natural logarithms can be used for precise computation of exponential curves, and are often used in time-constant circuit calculations.

## ALGEBRA

1. REAL AND IMAGINARY QUANTITIES - Real and imaginary quantities can be graphically represented by four positions of a unit vector, as shown in Figure 21. Positive real numbers are plotted to the right of the origin, and negative real numbers to the left along the horizontal axis, which is known as the AXIS OF REALS. Imaginaries which have POSITIVE signs are plotted above the origin and NEGATIVE imaginary quantities BELOW the origin along the vertical axis which is known as the axis of imaginaries.

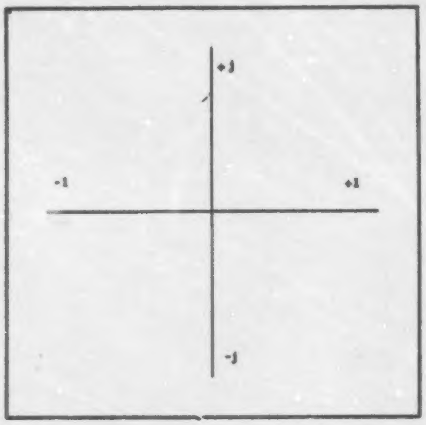


Figure 21. Positions of a Unit Vector

2. COMPLEX NUMBERS - A complex number is the sum of difference of a real quantity and an imaginary quantity; e.g., 5 -jb and 3 +j2 are complex numbers. The term complex number is really imappropriate because the system is not complex at all. Rectangular notation is a better designation. It is not difficult to apply the fundamental process to this special notation, for two or more complex numbers can be combined by combining the real portions and imaginary portions separately; e.g.:

a. ADDITION:

$$(1)\ \begin{array}{r} 5 + j3 \\ \underline{2 - j2} \\ 7 + j \end{array} \qquad (2)\ \begin{array}{r} 6 - j4 \\ \underline{-5 - j3} \\ 1 - j7 \end{array}$$

b. SUBTRACTION:

$$(1)\ \begin{array}{r} 5 + j3 \\ \underline{2 - j2} \\ 3 + j5 \end{array} \qquad (2)\ \begin{array}{r} 6 - j4 \\ \underline{-5 - j3} \\ 11 - j \end{array}$$

## Natural Logarithms

| | .00 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 0.0000 | 0.0100 | 0.0198 | 0.0296 | 0.0392 | 0.0488 | 0.0583 | 0.0677 | 0.0770 | 0.0862 |
| 1.1 | .0953 | .1044 | .1133 | .1222 | .1310 | .1398 | .1484 | .1570 | .1655 | .1740 |
| 1.2 | .1823 | .1906 | .1989 | .2070 | .2151 | .2231 | .2311 | .2390 | .2469 | .2546 |
| 1.3 | .2624 | .2700 | .2776 | .2852 | .2927 | .3001 | .3075 | .3148 | .3221 | .3293 |
| 1.4 | .3365 | .3436 | .3507 | .3577 | .3646 | .3716 | .3784 | .3853 | .3920 | .3988 |
| 1.5 | .4055 | .4121 | .4187 | .4253 | .4318 | .4383 | .4447 | .4511 | .4574 | .4637 |
| 1.6 | .4700 | .4762 | .4824 | .4886 | .4947 | .5008 | .5068 | .5128 | .5188 | .5247 |
| 1.7 | .5306 | .5365 | .5423 | .5481 | .5539 | .5596 | .5653 | .5710 | .5766 | .5822 |
| 1.8 | .5878 | .5933 | .5988 | .6043 | .6098 | .6152 | .6206 | .6259 | .6313 | .6366 |
| 1.9 | .6419 | .6471 | .6523 | .6575 | .6627 | .6678 | .6729 | .6780 | .6831 | .6881 |
| 2.0 | .6931 | .6981 | .7031 | .7080 | .7129 | .7178 | .7227 | .7275 | .7324 | .7372 |
| 2.1 | .7419 | .7467 | .7514 | .7561 | .7608 | .7655 | .7701 | .7747 | .7793 | .7839 |
| 2.2 | .7885 | .7930 | .7975 | .8020 | .8065 | .8109 | .8154 | .8198 | .8242 | .8286 |
| 2.3 | .8329 | .8372 | .8416 | .8459 | .8502 | .8544 | .8587 | .8629 | .8671 | .8713 |
| 2.4 | .8755 | .8796 | .8838 | .8879 | .8920 | .8961 | .9002 | .9042 | .9083 | .9123 |
| 2.5 | .9163 | .9203 | .9243 | .9282 | .9322 | .9361 | .9400 | .9439 | .9478 | .9517 |
| 2.6 | .9555 | .9594 | .9632 | .9670 | .9708 | .9746 | .9783 | .9821 | .9858 | .9895 |
| 2.7 | .9933 | .9969 | 1.0006 | 1.0043 | 1.0080 | 1.0116 | 1.0152 | 1.0188 | 1.0225 | 1.0260 |
| 2.8 | 1.0296 | 1.0332 | 1.0367 | 1.0403 | 1.0438 | 1.0473 | 1.0508 | 1.0543 | 1.0578 | 1.0613 |
| 2.9 | 1.0647 | 1.0682 | 1.0716 | 1.0750 | 1.0784 | 1.0818 | 1.0852 | 1.0886 | 1.0919 | 1.0953 |
| 3.0 | 1.0986 | 1.1019 | 1.1053 | 1.1086 | 1.1119 | 1.1151 | 1.1184 | 1.1217 | 1.1249 | 1.1282 |
| 3.1 | 1.1314 | 1.1346 | 1.1378 | 1.1410 | 1.1442 | 1.1474 | 1.1506 | 1.1537 | 1.1569 | 1.1600 |
| 3.2 | 1.1632 | 1.1663 | 1.1694 | 1.1725 | 1.1756 | 1.1787 | 1.1817 | 1.1848 | 1.1878 | 1.1909 |
| 3.3 | 1.1939 | 1.1969 | 1.2000 | 1.2030 | 1.2060 | 1.2090 | 1.2119 | 1.2149 | 1.2179 | 1.2208 |
| 3.4 | 1.2238 | 1.2267 | 1.2296 | 1.2326 | 1.2355 | 1.2384 | 1.2413 | 1.2442 | 1.2470 | 1.2499 |
| 3.5 | 1.2528 | 1.2556 | 1.2585 | 1.2613 | 1.2641 | 1.2669 | 1.2698 | 1.2726 | 1.2754 | 1.2782 |
| 3.6 | 1.2809 | 1.2837 | 1.2865 | 1.2892 | 1.2920 | 1.2947 | 1.2975 | 1.3002 | 1.3029 | 1.3056 |
| 3.7 | 1.3083 | 1.3110 | 1.3137 | 1.3164 | 1.3191 | 1.3318 | 1.3244 | 1.3271 | 1.3297 | 1.3324 |
| 3.8 | 1.3350 | 1.3376 | 1.3403 | 1.3429 | 1.3455 | 1.3481 | 1.3507 | 1.3533 | 1.3558 | 1.3584 |
| 3.9 | 1.3610 | 1.3635 | 1.3661 | 1.3686 | 1.3712 | 1.3737 | 1.3762 | 1.3788 | 1.3813 | 1.3838 |
| 4.0 | 1.3863 | 1.3888 | 1.3913 | 1.3938 | 1.3962 | 1.3987 | 1.4012 | 1.4036 | 1.4061 | 1.4085 |
| 4.1 | 1.4110 | 1.4134 | 1.4159 | 1.4183 | 1.4207 | 1.4231 | 1.4255 | 1.4279 | 1.4303 | 1.4327 |
| 4.2 | 1.4351 | 1.4375 | 1.4398 | 1.4422 | 1.4446 | 1.4469 | 1.4493 | 1.4516 | 1.4540 | 1.4563 |
| 4.3 | 1.4586 | 1.4609 | 1.4633 | 1.4656 | 1.4679 | 1.4702 | 1.4725 | 1.4748 | 1.4770 | 1.4793 |
| 4.4 | 1.4816 | 1.4839 | 1.4861 | 1.4884 | 1.4907 | 1.4929 | 1.4951 | 1.4974 | 1.4996 | 1.5019 |
| 4.5 | 1.5041 | 1.5063 | 1.5085 | 1.5107 | 1.5129 | 1.5151 | 1.5173 | 1.5195 | 1.5217 | 1.5239 |
| 4.6 | 1.5261 | 1.5282 | 1.5304 | 1.5326 | 1.5347 | 1.5369 | 1.5390 | 1.5412 | 1.5433 | 1.5454 |
| 4.7 | 1.5476 | 1.5497 | 1.5518 | 1.5539 | 1.5560 | 1.5581 | 1.5602 | 1.5623 | 1.5644 | 1.5665 |
| 4.8 | 1.5686 | 1.5707 | 1.5728 | 1.5748 | 1.5769 | 1.5790 | 1.5810 | 1.5831 | 1.5851 | 1.5872 |
| 4.9 | 1.5892 | 1.5913 | 1.5933 | 1.5953 | 1.5974 | 1.5994 | 1.6014 | 1.6034 | 1.6054 | 1.6074 |
| 5.0 | 1.6094 | 1.6114 | 1.6134 | 1.6154 | 1.6174 | 1.6194 | 1.6214 | 1.6233 | 1.6253 | 1.6273 |
| 5.1 | 1.6292 | 1.6312 | 1.6332 | 1.6351 | 1.6371 | 1.6390 | 1.6409 | 1.6429 | 1.6448 | 1.6467 |
| 5.2 | 1.6487 | 1.6506 | 1.6525 | 1.6544 | 1.6563 | 1.6582 | 1.6601 | 1.6620 | 1.6639 | 1.6658 |
| 5.3 | 1.6677 | 1.6696 | 1.6715 | 1.6734 | 1.6752 | 1.6771 | 1.6790 | 1.6808 | 1.6827 | 1.6845 |
| 5.4 | 1.6864 | 1.6882 | 1.6901 | 1.6919 | 1.6938 | 1.6956 | 1.6974 | 1.6993 | 1.7011 | 1.7029 |
| 5.5 | 1.7047 | 1.7066 | 1.7084 | 1.7102 | 1.7120 | 1.7138 | 1.7156 | 1.7174 | 1.7192 | 1.7210 |
| 5.6 | 1.7228 | 1.7246 | 1.7263 | 1.7281 | 1.7299 | 1.7317 | 1.7334 | 1.7352 | 1.7370 | 1.7387 |
| 5.7 | 1.7405 | 1.7422 | 1.7440 | 1.7457 | 1.7475 | 1.7492 | 1.7509 | 1.7527 | 1.7544 | 1.7561 |
| 5.8 | 1.7579 | 1.7596 | 1.7613 | 1.7630 | 1.7647 | 1.7664 | 1.7681 | 1.7699 | 1.7716 | 1.7733 |
| 5.9 | 1.7750 | 1.7766 | 1.7783 | 1.7800 | 1.7817 | 1.7843 | 1.7851 | 1.7867 | 1.7884 | 1.7901 |
| 6.0 | 1.7918 | 1.7934 | 1.7951 | 1.7967 | 1.7984 | 1.8001 | 1.8017 | 1.8034 | 1.8050 | 1.8066 |
| 6.1 | 1.8083 | 1.8099 | 1.8116 | 1.8132 | 1.8148 | 1.8165 | 1.8181 | 1.8197 | 1.8213 | 1.8229 |
| 6.2 | 1.8245 | 1.8262 | 1.8278 | 1.8294 | 1.8310 | 1.8326 | 1.8342 | 1.8358 | 1.8374 | 1.8390 |
| 6.3 | 1.8405 | 1.8421 | 1.8437 | 1.8453 | 1.8469 | 1.8485 | 1.8500 | 1.8516 | 1.8532 | 1.8547 |
| 6.4 | 1.8563 | 1.8579 | 1.8594 | 1.8610 | 1.8625 | 1.8641 | 1.8656 | 1.8672 | 1.8687 | 1.8703 |
| 6.5 | 1.8718 | 1.8733 | 1.8749 | 1.8764 | 1.8779 | 1.8795 | 1.8810 | 1.8825 | 1.8840 | 1.8856 |
| 6.6 | 1.8871 | 1.8886 | 1.8901 | 1.8916 | 1.8931 | 1.8946 | 1.8961 | 1.8976 | 1.8991 | 1.9006 |
| 6.7 | 1.9021 | 1.9036 | 1.9051 | 1.9066 | 1.9081 | 1.9095 | 1.9110 | 1.9125 | 1.9140 | 1.9155 |
| 6.8 | 1.9169 | 1.9184 | 1.9199 | 1.9213 | 1.9228 | 1.9242 | 1.9257 | 1.9272 | 1.9286 | 1.9301 |
| 6.9 | 1.9315 | 1.9330 | 1.9344 | 1.9359 | 1.9373 | 1.9387 | 1.9402 | 1.9416 | 1.9430 | 1.9445 |

Natural Logarithms (Continued)

| | .00 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.0 | 1.9459 | 1.9473 | 1.9488 | 1.9502 | 1.9516 | 1.9530 | 1.9544 | 1.9559 | 1.9573 | 1.9587 |
| 7.1 | 1.9601 | 1.9615 | 1.9629 | 1.9643 | 1.9657 | 1.9671 | 1.9685 | 1.9699 | 1.9713 | 1.9727 |
| 7.2 | 1.9741 | 1.9755 | 1.9769 | 1.9782 | 1.9796 | 1.9810 | 1.9824 | 1.9838 | 1.9851 | 1.9865 |
| 7.3 | 1.9879 | 1.9892 | 1.9906 | 1.9920 | 1.9933 | 1.9947 | 1.9961 | 1.9974 | 1.9988 | 2.0001 |
| 7.4 | 2.0015 | 2.0028 | 2.0042 | 2.0055 | 2.0069 | 2.0082 | 2.0096 | 2.0109 | 2.0122 | 2.0136 |
| 7.5 | 2.0149 | 2.0162 | 2.0176 | 2.0189 | 2.0202 | 2.0215 | 2.0229 | 2.0242 | 2.0255 | 2.0268 |
| 7.6 | 2.0281 | 2.0295 | 2.0308 | 2.0321 | 2.0334 | 2.0347 | 2.0360 | 2.0373 | 2.0386 | 2.0399 |
| 7.7 | 2.0410 | 2.0425 | 2.0438 | 2.0451 | 2.0464 | 2.0477 | 2.0490 | 2.0503 | 2.0516 | 2.0528 |
| 7.8 | 2.0541 | 2.0554 | 2.0567 | 2.0580 | 2.0592 | 2.0605 | 2.0618 | 2.0631 | 2.0643 | 2.0656 |
| 7.9 | 2.0669 | 2.0681 | 2.0694 | 2.0707 | 2.0719 | 2.0732 | 2.0744 | 2.0757 | 2.0769 | 2.0782 |
| 8.0 | 2.0794 | 2.0807 | 2.0819 | 2.0832 | 2.0844 | 2.0857 | 2.0869 | 2.0882 | 2.0894 | 2.0906 |
| 8.1 | 2.0919 | 2.0931 | 2.0943 | 2.0956 | 2.0968 | 2.0980 | 2.0992 | 2.1005 | 2.1017 | 2.1029 |
| 8.2 | 2.1041 | 2.1054 | 2.1066 | 2.1078 | 2.1090 | 2.1102 | 2.1114 | 2.1126 | 2.1138 | 2.1150 |
| 8.3 | 2.1163 | 2.1175 | 2.1187 | 2.1199 | 2.1211 | 2.1223 | 2.1235 | 2.1247 | 2.1258 | 2.1270 |
| 8.4 | 2.1282 | 2.1294 | 2.1306 | 2.1318 | 2.1330 | 2.1342 | 2.1353 | 2.1365 | 2.1377 | 2.1389 |
| 8.5 | 2.1401 | 2.1412 | 2.1424 | 2.1436 | 2.1448 | 2.1459 | 2.1471 | 2.1483 | 2.1494 | 2.1506 |
| 8.6 | 2.1518 | 2.1529 | 2.1541 | 2.1552 | 2.1564 | 2.1576 | 2.1587 | 2.1599 | 2.1610 | 2.1622 |
| 8.7 | 2.1633 | 2.1645 | 2.1656 | 2.1668 | 2.1679 | 2.1691 | 2.1702 | 2.1713 | 2.1725 | 2.1736 |
| 8.8 | 2.1748 | 2.1759 | 2.1770 | 2.1782 | 2.1793 | 2.1804 | 2.1815 | 2.1827 | 2.1838 | 2.1849 |
| 8.9 | 2.1861 | 2.1872 | 2.1883 | 2.1894 | 2.1905 | 2.1917 | 2.1928 | 2.1939 | 2.1950 | 2.1961 |
| 9.0 | 2.1972 | 2.1983 | 2.1994 | 2.2006 | 2.2017 | 2.2028 | 2.2039 | 2.2050 | 2.2061 | 2.2072 |
| 9.1 | 2.2083 | 2.2094 | 2.2105 | 2.2116 | 2.2127 | 2.2138 | 2.2148 | 2.2159 | 2.2170 | 2.2181 |
| 9.2 | 2.2192 | 2.2203 | 2.2214 | 2.2225 | 2.2235 | 2.2246 | 2.2257 | 2.2268 | 2.2279 | 2.2289 |
| 9.3 | 2.2300 | 2.2311 | 2.2322 | 2.2332 | 2.2343 | 2.2354 | 2.2364 | 2.2375 | 2.2386 | 2.2396 |
| 9.4 | 2.2407 | 2.2418 | 2.2428 | 2.2439 | 2.2450 | 2.2460 | 2.2471 | 2.2481 | 2.2492 | 2.2502 |
| 9.5 | 2.2513 | 2.2523 | 2.2534 | 2.2544 | 2.2555 | 2.2565 | 2.2576 | 2.2586 | 2.2597 | 2.2607 |
| 9.6 | 2.2618 | 2.2628 | 2.2638 | 2.2649 | 2.2659 | 2.2670 | 2.2680 | 2.2690 | 2.2701 | 2.2711 |
| 9.7 | 2.2721 | 2.2732 | 2.2742 | 2.2752 | 2.2762 | 2.2773 | 2.2783 | 2.2793 | 2.2803 | 2.2814 |
| 9.8 | 2.2824 | 2.2834 | 2.2844 | 2.2854 | 2.2865 | 2.2875 | 2.2885 | 2.2895 | 2.2905 | 2.2915 |
| 9.9 | 2.2925 | 2.2935 | 2.2946 | 2.2956 | 2.2966 | 2.2976 | 2.2986 | 2.2996 | 2.3006 | 2.3016 |
| 10.0 | 2.3026 | | | | | | | | | |

## Exponential Functions

| X | FUNCTION | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 1.0000<br>1.0000 | 1.0101<br>0.9900 | 1.0202<br>0.9802 | 1.0305<br>0.9704 | 1.0408<br>0.9608 | 1.0513<br>0.9512 | 1.0618<br>0.9418 | 1.0725<br>0.9324 | 1.0833<br>0.9231 | 1.0942<br>0.9139 |
| 0.1 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 1.1052<br>0.9048 | 1.1163<br>0.8958 | 1.1275<br>0.8869 | 1.1388<br>0.8781 | 1.1503<br>0.8694 | 1.1618<br>0.8607 | 1.1735<br>0.8521 | 1.1853<br>0.8437 | 1.1972<br>0.8353 | 1.2092<br>0.8270 |
| 0.2 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 1.2214<br>0.8187 | 1.2337<br>0.8106 | 1.2461<br>0.8025 | 1.2586<br>0.7945 | 1.2712<br>0.7866 | 1.2840<br>0.7788 | 1.2969<br>0.7711 | 1.3100<br>0.7634 | 1.3231<br>0.7558 | 1.3364<br>0.7483 |
| 0.3 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 1.3499<br>0.7408 | 1.3634<br>0.7334 | 1.3771<br>0.7261 | 1.3910<br>0.7189 | 1.4049<br>0.7118 | 1.4191<br>0.7047 | 1.4333<br>0.6977 | 1.4477<br>0.6907 | 1.4623<br>0.6839 | 1.4770<br>0.6771 |
| 0.4 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 1.4918<br>0.6703 | 1.5068<br>0.6637 | 1.5220<br>0.6570 | 1.5373<br>0.6505 | 1.5527<br>0.6440 | 1.5683<br>0.6376 | 1.5841<br>0.6313 | 1.6000<br>0.6250 | 1.6161<br>0.6188 | 1.6323<br>0.6126 |
| 0.5 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 1.6487<br>0.6065 | 1.6653<br>0.6005 | 1.6820<br>0.5945 | 1.6989<br>0.5886 | 1.7160<br>0.5827 | 1.7333<br>0.5769 | 1.7507<br>0.5712 | 1.7683<br>0.5655 | 1.7860<br>0.5599 | 1.8040<br>0.5543 |
| 0.6 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 1.8221<br>0.5488 | 1.8404<br>0.5434 | 1.8589<br>0.5379 | 1.8776<br>0.5326 | 1.8965<br>0.5273 | 1.9155<br>0.5220 | 1.9348<br>0.5169 | 1.9542<br>0.5117 | 1.9739<br>0.5066 | 1.9937<br>0.5017 |
| 0.7 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 2.0138<br>0.4966 | 0.0340<br>0.4916 | 2.0544<br>0.4868 | 2.0751<br>0.4819 | 2.0959<br>0.4771 | 2.1170<br>0.4724 | 2.1383<br>0.4677 | 2.1598<br>0.4630 | 2.1815<br>0.4584 | 2.2034<br>0.4538 |
| 0.8 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 2.2255<br>0.4493 | 2.2479<br>0.4449 | 2.2705<br>0.4404 | 2.2933<br>0.4360 | 2.3164<br>0.4317 | 2.3396<br>0.4274 | 2.3632<br>0.4232 | 2.3869<br>0.4190 | 2.4109<br>0.4148 | 2.4351<br>0.4107 |
| 0.9 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 2.4596<br>0.4066 | 2.4843<br>0.4025 | 2.5093<br>0.3985 | 2.5345<br>0.3946 | 2.5600<br>0.3906 | 2.5857<br>0.3867 | 2.6117<br>0.3829 | 2.6379<br>0.3791 | 2.6645<br>0.3753 | 2.6912<br>0.3716 |
| 1.0 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 2.7183<br>0.3679 | 2.7456<br>0.3642 | 2.7732<br>0.3606 | 2.8011<br>0.3570 | 2.8292<br>0.3535 | 2.8577<br>0.3499 | 2.8864<br>0.3465 | 2.9154<br>0.3430 | 2.9447<br>0.3396 | 2.9743<br>0.3362 |
| 1.1 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 3.0042<br>0.3329 | 3.0344<br>0.3296 | 3.0649<br>0.3263 | 3.0957<br>0.3230 | 3.1268<br>0.3198 | 3.1582<br>0.3166 | 3.1899<br>0.3135 | 3.2220<br>0.3104 | 3.2544<br>0.3073 | 3.2871<br>0.3042 |
| 1.2 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 3.3201<br>0.3012 | 3.3535<br>0.2982 | 3.3872<br>0.2952 | 3.4212<br>0.2923 | 3.4556<br>0.2894 | 3.4903<br>0.2865 | 3.5254<br>0.2837 | 3.5609<br>0.2808 | 3.5966<br>0.2780 | 3.6328<br>0.2753 |
| 1.3 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 3.6693<br>0.2725 | 3.7062<br>0.2698 | 3.7434<br>0.2671 | 3.7810<br>0.2645 | 3.8190<br>0.2618 | 3.8574<br>0.2592 | 3.8962<br>0.2567 | 3.9354<br>0.2541 | 3.9749<br>0.2516 | 4.0149<br>0.2491 |
| 1.4 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 4.0552<br>0.2466 | 4.0960<br>0.2441 | 4.1371<br>0.2417 | 4.1787<br>0.2393 | 4.2207<br>0.2369 | 4.2631<br>0.2346 | 4.3060<br>0.2322 | 4.3492<br>0.2299 | 4.3929<br>0.2276 | 4.4371<br>0.2254 |
| 1.5 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 4.4817<br>0.2231 | 4.5267<br>0.2209 | 4.5722<br>0.2187 | 4.6182<br>0.2165 | 4.6646<br>0.2144 | 4.7115<br>0.2122 | 4.7588<br>0.2101 | 4.8066<br>0.2080 | 4.8550<br>0.2060 | 4.9037<br>0.2039 |
| 1.6 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 4.9530<br>0.2019 | 5.0028<br>0.1999 | 5.0531<br>0.1979 | 5.1039<br>0.1959 | 5.1552<br>0.1940 | 5.2070<br>0.1920 | 5.2593<br>0.1901 | 5.3122<br>0.1882 | 5.3656<br>0.1864 | 5.4195<br>0.1845 |
| 1.7 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 5.4739<br>0.1827 | 5.5290<br>0.1809 | 5.5845<br>0.1791 | 5.6407<br>0.1773 | 5.6973<br>0.1755 | 5.7546<br>0.1738 | 5.8124<br>0.1720 | 5.8709<br>0.1703 | 5.9299<br>0.1686 | 5.9895<br>0.1670 |
| 1.8 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 6.0496<br>0.1653 | 6.1104<br>0.1637 | 6.1719<br>0.1620 | 6.2339<br>0.1604 | 6.2965<br>0.1588 | 6.3598<br>0.1572 | 6.4237<br>0.1557 | 6.4883<br>0.1541 | 6.5535<br>0.1526 | 6.6194<br>0.1511 |
| 1.9 | $\epsilon^{X}$<br>$\epsilon^{-X}$ | 6.6859<br>0.1496 | 6.7531<br>0.1481 | 6.8210<br>0.1466 | 6.8895<br>0.1451 | 6.9588<br>0.1437 | 7.0287<br>0.1423 | 7.0993<br>0.1409 | 7.1707<br>0.1395 | 7.2427<br>0.1381 | 7.3155<br>0.1367 |

### Exponential Functions (Continued)

| X | FUNCTION | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.0 | $\epsilon^X$<br>$\epsilon^{-X}$ | 7.3891<br>0.1353 | 7.4633<br>0.1340 | 7.5383<br>0.1327 | 7.6141<br>0.1313 | 7.6906<br>0.1300 | 7.7679<br>0.1287 | 7.8460<br>0.1275 | 7.9248<br>0.1262 | 8.0045<br>0.1249 | 8.0849<br>0.1237 |
| 2.1 | $\epsilon^X$<br>$\epsilon^{-X}$ | 8.1662<br>0.1225 | 8.2482<br>0.1212 | 8.3311<br>0.1200 | 8.4149<br>0.1188 | 8.4994<br>0.1177 | 8.5849<br>0.1165 | 8.6711<br>0.1153 | 8.7583<br>0.1142 | 8.8463<br>0.1130 | 8.9352<br>0.1119 |
| 2.2 | $\epsilon^X$<br>$\epsilon^{-X}$ | 9.0250<br>0.1108 | 9.1157<br>0.1097 | 9.2073<br>0.1086 | 9.2999<br>0.1075 | 9.3933<br>0.1065 | 9.4877<br>0.1054 | 9.5831<br>0.1044 | 9.6794<br>0.1033 | 9.7767<br>0.1023 | 9.8749<br>0.1013 |
| 2.3 | $\epsilon^X$<br>$\epsilon^{-X}$ | 9.9742<br>0.1003 | 10.074<br>0.0993 | 10.176<br>0.0983 | 10.278<br>0.0973 | 10.381<br>0.0963 | 10.486<br>0.0954 | 10.591<br>0.0944 | 10.697<br>0.0935 | 10.805<br>0.0926 | 10.913<br>0.0916 |
| 2.4 | $\epsilon^X$<br>$\epsilon^{-X}$ | 11.023<br>0.0907 | 11.134<br>0.0898 | 11.246<br>0.0889 | 11.359<br>0.0880 | 11.473<br>0.0872 | 11.588<br>0.0863 | 11.705<br>0.0854 | 11.822<br>0.0846 | 11.941<br>0.0837 | 12.061<br>0.0829 |
| 2.5 | $\epsilon^X$<br>$\epsilon^{-X}$ | 12.182<br>0.0821 | 12.305<br>0.0813 | 12.429<br>0.0805 | 12.554<br>0.0797 | 12.680<br>0.0789 | 12.807<br>0.0781 | 12.936<br>0.0773 | 13.066<br>0.0765 | 13.197<br>0.0758 | 13.330<br>0.0750 |
| 2.6 | $\epsilon^X$<br>$\epsilon^{-X}$ | 13.464<br>0.0743 | 13.599<br>0.0735 | 13.736<br>0.0728 | 13.874<br>0.0721 | 14.013<br>0.0714 | 14.154<br>0.0707 | 14.296<br>0.0699 | 14.440<br>0.0693 | 14.585<br>0.0686 | 14.732<br>0.0679 |
| 2.7 | $\epsilon^X$<br>$\epsilon^{-X}$ | 14.880<br>0.0672 | 15.029<br>0.0665 | 15.180<br>0.0659 | 15.333<br>0.0652 | 15.487<br>0.0646 | 15.643<br>0.0639 | 15.800<br>0.0633 | 15.959<br>0.0627 | 16.119<br>0.0620 | 16.281<br>0.0614 |
| 2.8 | $\epsilon^X$<br>$\epsilon^{-X}$ | 16.445<br>0.0608 | 16.610<br>0.0602 | 16.777<br>0.0596 | 16.945<br>0.0590 | 17.116<br>0.0584 | 17.288<br>0.0578 | 17.462<br>0.0573 | 17.637<br>0.0567 | 17.814<br>0.0561 | 17.993<br>0.0556 |
| 2.9 | $\epsilon^X$<br>$\epsilon^{-X}$ | 18.174<br>0.0550 | 18.357<br>0.0545 | 18.541<br>0.0539 | 18.728<br>0.0534 | 18.916<br>0.0529 | 19.106<br>0.0523 | 19.298<br>0.0518 | 19.492<br>0.0513 | 19.688<br>0.0508 | 19.886<br>0.0503 |
| 3.0 | $\epsilon^X$<br>$\epsilon^{-X}$ | 20.086<br>0.0498 | 20.287<br>0.0493 | 20.491<br>0.0488 | 20.697<br>0.0483 | 20.905<br>0.0478 | 21.115<br>0.0474 | 21.328<br>0.0469 | 21.542<br>0.0464 | 21.758<br>0.0460 | 21.977<br>0.0455 |
| 3.1 | $\epsilon^X$<br>$\epsilon^{-X}$ | 22.198<br>0.0450 | 22.421<br>0.0446 | 22.646<br>0.0442 | 22.874<br>0.0437 | 23.104<br>0.0433 | 23.336<br>0.0429 | 23.571<br>0.0424 | 23.807<br>0.0420 | 24.047<br>0.0416 | 24.288<br>0.0412 |
| 3.2 | $\epsilon^X$<br>$\epsilon^{-X}$ | 24.533<br>0.0408 | 24.779<br>0.0404 | 25.028<br>0.0400 | 25.280<br>0.0396 | 25.534<br>0.0392 | 25.790<br>0.0388 | 26.050<br>0.0384 | 26.311<br>0.0380 | 26.576<br>0.0376 | 26.843<br>0.0373 |
| 3.3 | $\epsilon^X$<br>$\epsilon^{-X}$ | 27.113<br>0.0369 | 27.385<br>0.0365 | 27.660<br>0.0362 | 27.938<br>0.0358 | 28.219<br>0.0354 | 28.503<br>0.0351 | 28.789<br>0.0347 | 29.079<br>0.0344 | 29.371<br>0.0340 | 29.666<br>0.0337 |
| 3.4 | $\epsilon^X$<br>$\epsilon^{-X}$ | 29.964<br>0.0334 | 30.265<br>0.0330 | 30.569<br>0.0327 | 30.877<br>0.0324 | 31.187<br>0.0321 | 31.500<br>0.0317 | 31.817<br>0.0314 | 32.137<br>0.0311 | 32.460<br>0.0308 | 32.786<br>0.0305 |
| 3.5 | $\epsilon^X$<br>$\epsilon^{-X}$ | 33.115<br>0.0302 | 33.448<br>0.0299 | 33.784<br>0.0296 | 34.124<br>0.0293 | 34.467<br>0.0290 | 34.813<br>0.0287 | 35.163<br>0.0284 | 35.517<br>0.0282 | 35.874<br>0.0279 | 36.234<br>0.0276 |
| 3.6 | $\epsilon^X$<br>$\epsilon^{-X}$ | 36.598<br>0.0273 | 36.966<br>0.0271 | 37.338<br>0.0268 | 37.713<br>0.0265 | 38.092<br>0.0263 | 38.475<br>0.0260 | 38.861<br>0.0257 | 39.252<br>0.0255 | 39.646<br>0.0252 | 40.045<br>0.0250 |
| 3.7 | $\epsilon^X$<br>$\epsilon^{-X}$ | 40.447<br>0.0347 | 40.854<br>0.0245 | 41.264<br>0.0242 | 41.679<br>0.0240 | 42.098<br>0.0238 | 42.521<br>0.0225 | 42.948<br>0.0233 | 43.380<br>0.0231 | 43.816<br>0.0228 | 44.256<br>0.0226 |
| 3.8 | $\epsilon^X$<br>$\epsilon^{-X}$ | 44.701<br>0.0224 | 45.150<br>0.0221 | 45.604<br>0.0219 | 46.063<br>0.0217 | 46.525<br>0.0215 | 46.993<br>0.0213 | 47.465<br>0.0211 | 47.942<br>0.0209 | 48.424<br>0.0207 | 48.911<br>0.0204 |
| 3.9 | $\epsilon^X$<br>$\epsilon^{-X}$ | 49.402<br>0.0202 | 49.899<br>0.0200 | 50.400<br>0.0198 | 50.907<br>0.0196 | 51.419<br>0.0195 | 51.935<br>0.0193 | 52.457<br>0.0191 | 52.985<br>0.0189 | 53.517<br>0.0187 | 54.055<br>0.0185 |

## Exponential Functions (Continued)

| X | FUNCTION | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.0 | $\epsilon^X$<br>$\epsilon^{-X}$ | 54.598<br>0.0183 | 55.147<br>0.0181 | 55.701<br>0.0180 | 56.261<br>0.0178 | 56.826<br>0.0176 | 57.397<br>0.0174 | 57.974<br>0.0172 | 58.557<br>0.0171 | 59.145<br>0.0169 | 59.740<br>0.0167 |
| 4.1 | $\epsilon^X$<br>$\epsilon^{-X}$ | 60.340<br>0.0166 | 60.947<br>0.0164 | 61.559<br>0.0162 | 52.178<br>0.0161 | 62.803<br>0.0159 | 63.434<br>0.0158 | 64.072<br>0.0156 | 64.715<br>0.0155 | 65.366<br>0.0153 | 66.023<br>0.0151 |
| 4.2 | $\epsilon^X$<br>$\epsilon^{-X}$ | 66.686<br>0.0150 | 67.357<br>0.0148 | 68.033<br>0.0147 | 68.717<br>0.0146 | 69.408<br>0.0144 | 70.105<br>0.0143 | 70.810<br>0.0141 | 71.522<br>0.0140 | 72.240<br>0.0138 | 72.966<br>0.0137 |
| 4.3 | $\epsilon^X$<br>$\epsilon^{-X}$ | 73.700<br>0.0136 | 74.440<br>0.0134 | 75.189<br>0.0133 | 75.944<br>0.0132 | 76.708<br>0.0130 | 77.478<br>0.0129 | 78.257<br>0.0128 | 79.044<br>0.0127 | 79.838<br>0.0125 | 80.640<br>0.0124 |
| 4.4 | $\epsilon^X$<br>$\epsilon^{-X}$ | 81.451<br>0.0123 | 82.269<br>0.0122 | 83.096<br>0.0120 | 83.931<br>0.0119 | 84.775<br>0.0118 | 85.627<br>0.0117 | 86.488<br>0.0116 | 87.357<br>0.0114 | 88.235<br>0.0113 | 89.121<br>0.0112 |
| 4.5 | $\epsilon^X$<br>$\epsilon^{-X}$ | 90.017<br>0.0111 | 90.922<br>0.0110 | 91.836<br>0.0109 | 92.759<br>0.0108 | 93.691<br>0.0107 | 94.632<br>0.0106 | 95.583<br>0.0105 | 96.544<br>0.0104 | 97.514<br>0.0103 | 98.494<br>0.0102 |
| 4.6 | $\epsilon^X$<br>$\epsilon^{-X}$ | 99.484<br>0.0101 | 100.48<br>0.0100 | 101.49<br>0.0099 | 102.51<br>0.0098 | 103.54<br>0.0097 | 104.58<br>0.0096 | 105.64<br>0.0095 | 106.70<br>0.0094 | 107.77<br>0.0093 | 108.85<br>0.0092 |
| 4.7 | $\epsilon^X$<br>$\epsilon^{-X}$ | 109.95<br>0.0091 | 111.05<br>0.0090 | 112.17<br>0.0089 | 113.30<br>0.0088 | 114.43<br>0.0087 | 115.58<br>0.0087 | 116.75<br>0.0086 | 117.92<br>0.0085 | 119.10<br>0.0084 | 120.30<br>0.0083 |
| 4.8 | $\epsilon^X$<br>$\epsilon^{-X}$ | 121.51<br>0.0082 | 122.73<br>0.0081 | 123.97<br>0.0081 | 125.21<br>0.0080 | 126.47<br>0.0079 | 127.74<br>0.0078 | 129.02<br>0.0078 | 130.32<br>0.0077 | 131.63<br>0.0076 | 132.95<br>0.0075 |
| 4.9 | $\epsilon^X$<br>$\epsilon^{-X}$ | 134.29<br>0.0074 | 135.64<br>0.0074 | 137.00<br>0.0073 | 138.38<br>0.0072 | 139.77<br>0.0072 | 141.17<br>0.0071 | 142.59<br>0.0070 | 144.03<br>0.0069 | 145.47<br>0.0069 | 146.94<br>0.0068 |
| 5.0 | $\epsilon^X$<br>$\epsilon^{-X}$ | 148.41<br>0.0067 | 149.90<br>0.0067 | 151.41<br>0.0066 | 152.93<br>0.0065 | 154.47<br>0.0065 | 156.02<br>0.0064 | 157.59<br>0.0063 | 159.17<br>0.0063 | 160.77<br>0.0062 | 162.39<br>0.0062 |
| 5.1 | $\epsilon^X$<br>$\epsilon^{-X}$ | 164.02<br>0.0061 | 165.67<br>0.0060 | 167.34<br>0.0060 | 169.02<br>0.0059 | 170.73<br>0.0059 | 172.43<br>0.0058 | 174.16<br>0.0057 | 175.91<br>0.0057 | 177.68<br>0.0056 | 179.47<br>0.0056 |
| 5.2 | $\epsilon^X$<br>$\epsilon^{-X}$ | 181.27<br>0.0055 | 183.09<br>0.0055 | 184.93<br>0.0054 | 186.79<br>0.0054 | 188.67<br>0.0053 | 190.57<br>0.0052 | 192.48<br>0.0052 | 194.42<br>0.0051 | 196.37<br>0.0051 | 198.34<br>0.0050 |
| 5.3 | $\epsilon^X$<br>$\epsilon^{-X}$ | 200.34<br>0.0050 | 202.35<br>0.0049 | 204.38<br>0.0049 | 206.44<br>0.0048 | 208.51<br>0.0048 | 210.61<br>0.0047 | 212.72<br>0.0047 | 214.86<br>0.0047 | 217.02<br>0.0046 | 219.20<br>0.0046 |
| 5.4 | $\epsilon^X$<br>$\epsilon^{-X}$ | 221.41<br>0.0045 | 223.63<br>0.0045 | 225.88<br>0.0044 | 228.15<br>0.0044 | 230.44<br>0.0043 | 232.76<br>0.0043 | 235.10<br>0.0043 | 237.46<br>0.0042 | 239.85<br>0.0042 | 242.26<br>0.0041 |
| 5.5 | $\epsilon^X$<br>$\epsilon^{-X}$ | 244.69<br>0.0041 | 247.15<br>0.0040 | 249.64<br>0.0040 | 252.14<br>0.0040 | 254.68<br>0.0039 | 257.24<br>0.0039 | 259.82<br>0.0038 | 262.43<br>0.0038 | 265.07<br>0.0038 | 267.74<br>0.0037 |
| 5.6 | $\epsilon^X$<br>$\epsilon^{-X}$ | 270.43<br>0.0037 | 273.14<br>0.0037 | 275.89<br>0.0036 | 278.66<br>0.0036 | 281.46<br>0.0036 | 284.29<br>0.0035 | 287.15<br>0.0035 | 290.03<br>0.0034 | 292.95<br>0.0034 | 295.89<br>0.0034 |
| 5.7 | $\epsilon^X$<br>$\epsilon^{-X}$ | 298.87<br>0.0033 | 301.87<br>0.0033 | 304.90<br>0.0033 | 307.97<br>0.0032 | 311.06<br>0.0032 | 314.19<br>0.0032 | 317.35<br>0.0032 | 320.54<br>0.0031 | 323.76<br>0.0031 | 327.01<br>0.0031 |
| 5.8 | $\epsilon^X$<br>$\epsilon^{-X}$ | 330.30<br>0.0030 | 333.62<br>0.0030 | 336.97<br>0.0030 | 340.36<br>0.0029 | 343.78<br>0.0029 | 347.23<br>0.0029 | 350.72<br>0.0029 | 354.25<br>0.0028 | 357.81<br>0.0028 | 361.41<br>0.0028 |
| 5.9 | $\epsilon^X$<br>$\epsilon^{-X}$ | 365.04<br>0.0027 | 368.71<br>0.0027 | 372.41<br>0.0027 | 376.15<br>0.0027 | 379.93<br>0.0026 | 383.75<br>0.0026 | 387.61<br>0.0026 | 391.51<br>0.0026 | 395.44<br>0.0025 | 399.41<br>0.0025 |

c. MULTIPLICATION - To multiply complex numbers, use the same procedure as with bionomials, except that where $j^2$ occurs in the final result, you replace it by its equivalent, -1; e.g.:

Multiply 5 + j3 by 2 - j2

$$\begin{array}{r} 5 + j3 \\ \underline{2 - j2} \\ \\ 10 + j6 \qquad\quad \\ \underline{\quad - j10 - j^2 6} \\ \\ 10 - j4 \;\; - j^2 6 \end{array}$$

$$= 10 - j4 - (-1)\,(6) = 10 - j4 + 6 = 16 - j4$$

d. DIVISION - Divide one rectangular quantity (complex number) by another by rationalizing the denominator, then dividing the real number into the numerator. Remember that you rationalize the denominator by multiplying both numerator and denominator by the conjugate of the denominator; e.g.:

(1) Divide (5 + j3) by (2 - j2)

$$\frac{5 + j3}{2 - j2} \times \frac{2 + j2}{2 + j2} = \frac{10 + j16 + j^2 6}{4 - j^2 4} =$$

$$\frac{10 + j16 - 6}{4 + 4} = \frac{4 + j16}{8} = \frac{1 + j4}{2} \text{ or } 0.5 + j2$$

(2) Divide (6 - j4) by (-5 - j3)

$$\frac{6 - j4}{-5 - j3} \times \frac{-5 + j3}{-5 + j3} = \frac{-30 + j38 - j^2 12}{25 - j^2 9} =$$

$$\frac{-30 + j38 + 12}{25 + 9} = \frac{-18 + j38}{34} = \frac{-9 + j19}{17}$$

3. QUANDRATIC EQUATIONS - The degree of an equation in which the unknown has only positive integral exponents and does not appear in the denominator of a fraction is the same as its term of highest degree. The degree of a term in a letter means its exponent in that term. To illustrate, the degree of the term $4x^2y^3$ in x is the second. The equation $ax^2 + bx + c = 0$ is a second degree or quadriatic equation in x. The following discusses the solution of equations of this form: there are several methods you can use to solve a quadratic equation, such as graphing, completing the square, factoring, and using a formula derived from the general form $ax^2 + bx + c = 0$ by the completion of the square method. The formula is

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

where a, b, and c are, respectively the coefficient of $x^2$, the coefficient of x, and the term which does not contain x. Before applying the formula, always put the equation in the standard form $ax^2 + bx + c = 0$ by transposition. The following examples illustrate the processes for solving quadratic equations by the formula:

a. Solve for x in the equation $3x^2 + 8x - 10 = 0$:

By the formula,

$$x = \frac{-8 \pm \sqrt{64 + 120}}{6} = \frac{-8 \pm \sqrt{184}}{6} =$$

$$\frac{-8 \pm 13.56}{6} = \frac{-21.56}{6} \text{ or } \frac{5.56}{6} = -3.59 \text{ or } 0.93$$

b. Solve for a in the equation $2a = 3a^2 - 8$:

Subtract $3a^2$ from both sides: $-3a^2 + 2a = -8$

Add 8 to both sides: $-3a^2 + 2a + 8 = 0$

By formula:

$$a = \frac{-2 \pm \sqrt{4 + 96}}{-6} = \frac{-2 \pm \sqrt{100}}{-6} =$$

$$\frac{-2 \pm 10}{-6} = \frac{-12}{-6} \text{ or } \frac{8}{-6} = 2 \text{ or } -1.33$$

c. Solve for R in the equation

$$\frac{R^2}{R + 5} = \frac{R}{3} + \frac{5}{6}$$

$$6R^2 = 2R(R + 5) + 5(R + 5)$$

$$6R^2 = 2R^2 + 10R + 5R + 25$$

$$6R^2 = 2R^2 + 15R + 25$$

$$4R^2 - 15R - 25 = 0$$

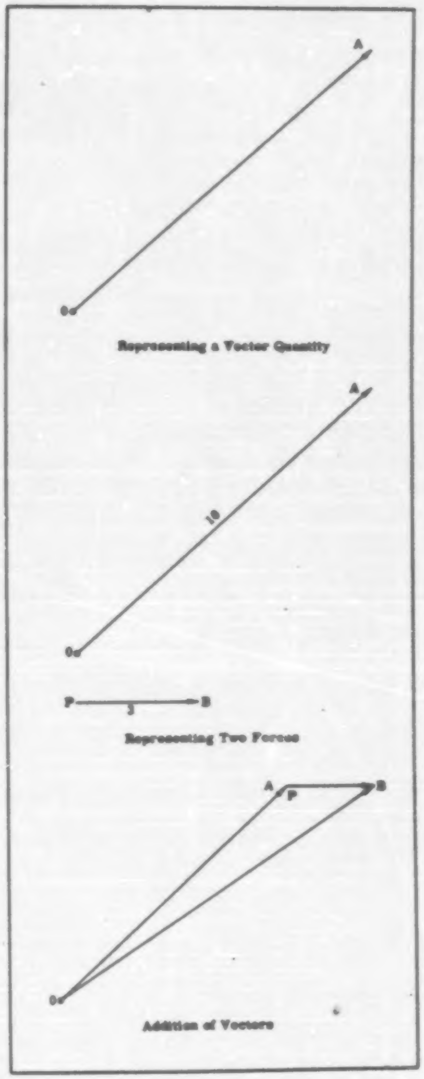
$$R = \frac{15 \pm \sqrt{225 + 400}}{8} =$$

$$\frac{15 \pm \sqrt{625}}{8} = \frac{15 \pm 25}{8} = \frac{40}{8} \text{ or } \frac{-10}{8} = 5 \text{ or } -1.25$$

The quantity $b^2 - 4ac$ which appears under the radical in the formula is called DISCRIMINANT. It indicates the type of roots. If $b^2 - 4ac$ is positive, there are two real and unequal roots; if $b^2 - 4ac$ is negative, the roots are imaginary and unequal; if $b^2 - 4ac$ equals zero, the roots are real and equal.

**4. VECTOR QUANTITIES AND VECTOR ALGEBRA** - Some quantities have magnitude only while others have both magnitude and direction. Quantities with magnitude only are known as scalar quantities; those with both magnitude and direction, as vector quantities. Forces, motion, and acceleration are examples of vector quantities. Scalar quantities may be added, subtracted, or multiplied directly. But since a second dimension enters into vector quantities, a number of special methods must be employed in dealing with vector quantities:

a. Representing a Vector Quantity - A vector quantity may be represented by a line segment. The length of the line indicates the magnitude and its angular position and an arrow point indicates the direction as shown in Figure 22. Usually this vector is called the vector OA. Other common notations, to indicate vector quantities, are M; M and M.



Representing a Vector Quantity

Representing Two Forces

Addition of Vectors

Figure 22. Vector Quantities

b. Representing Two Forces - Vector quantities may be combined, as you see in the illustrations. Suppose the two vectors OA and PB represent two forces applied to the same object. OA might be the force on an airplane due to the action of its engines and PB the force due to the wind. The vector sum of OA and PB is obtained by placing PB, without changing its magnitude or direction, so that P coincides with A. Then OB is the vector sum and represents the magnitude and direction of the resultant forces.

c. Addition of Vectors - You can obtain the same result by an alternate method. If you place the two vectors at the origin, and form a parallelogram with OA and OB as adjacent sides, the diagonal will be the resultant force. This is referred to as the parallelogram law of forces and may be applied to the addition of any set of vector quantities (Figure 23).

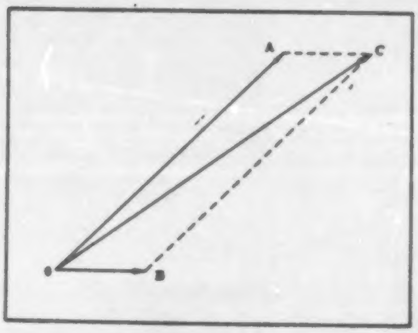


Figure 23. Parallelogram Method of Adding Vectors

d. Polar or Rectangular Form of a Vector - You can describe a vector in POLAR form or in RECTANGULAR form. The polar form shows the magnitude of the vector and the angle which it makes with the horizontal axis. For example, $10\underline{/30}°$ describes a vector 10 units in length and at an angle of 30°. In the rectangular form, the vector is resolved into two components which are the projections of the vector on the horizontal and vertical axis and have as their origin the initial point of the vector as in Figure 24. In this work, you can designate the horizontal component as the real component and the vertical component as the IMAGINARY or j component. From the relations in the definitions of sine and cosine, ($\sin \theta = x/z$ and $\cos \theta = r/z$) you can see that $r = z \cos \theta$ and $x = z \sin \theta$. Thus, $z\underline{/\theta} = z \cos \theta + jz \sin \theta$. Hence the vector $10\underline{/30}° = 8.66 + j5$.

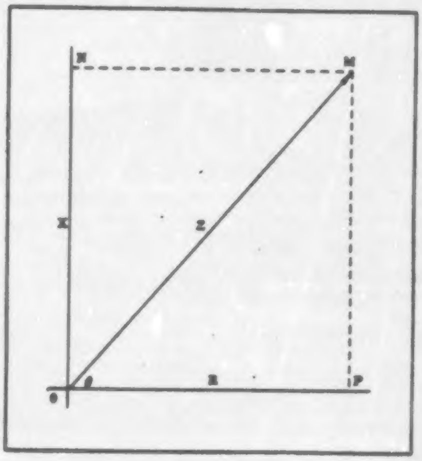


Figure 24. Components of a Vector

(1) Addition and Subtraction - You have already observed how complex quantities (such as rectangular forms of vectors in Figure 25) can be added and subtracted. Since the addition of vectors by graphical means, as described before, is not satisfactory unless you use accurate instruments to construct the vectors, the usual method of combining two vectors is to convert them to rectangular form and to add them algebraically:

(a) Add $35\underline{/40}°$ and $47\underline{/55}°$.

$$35\underline{/40}° = 35 \cos 40° + j35 \sin 40°$$

$$= 35(.7660) + j\,35\,(.6428)$$

$$= 26.81 + j22.50$$

$$47\underline{/55}° = 47 \cos 55° + j47 \sin 55°$$

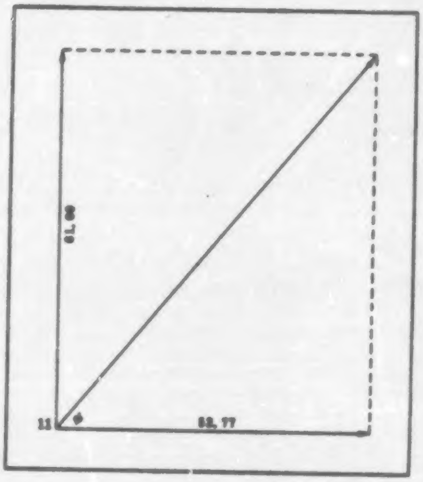


Figure 25. Graphical Addition of Vectors

$= 47\ (.5736) + j47\ (.8192)$

$= 26.96 + j38.50$

ADDING:

$$\begin{array}{r} 26.81 + j22.50 \\ \underline{29.96 + j38.50} \end{array}$$

The sum is $\quad 53.77 + j61.00$

The graphical addition of the vectors in this example is shown in Figure 25. To convert this result to polar form, remember that

$$\frac{x}{r} = \tan \theta$$

Therefore tan θ in this case is $\frac{61.00}{53.77} = 1.134$, and $\theta = \text{arc tan } 1.1343 = 48.6^\circ$. Since $\cos \theta = \frac{r}{z}$, $z = \frac{r}{\cos \theta} = \frac{53.77}{\cos 48.6^\circ} = \frac{53.77}{.6613} = 81.3$. In polar form the answer is $81.5\underline{/48.6^\circ}$.

(b) Subtract:

$$45.6\underline{/21.5^\circ} \text{ from } 51.4\underline{/-10.5^\circ}$$

$$45.6\underline{/21.5^\circ} = 45.6 \cos 21.5^\circ + j45.6$$

$$\sin 21.5^\circ = 45.6\ (.9304) + j45.6\ (13665)$$

$$= 42.4 + j16.7$$

$$51.4\underline{/-10.5^\circ} =$$

$$51.4 \cos (10.5^\circ) + j51.4 \sin (-10.5^\circ) =$$

$$51.4\ (.9833) + j51.4\ (-.1822) = 50.5 - j9.36$$

SUBTRACTING:

$$\begin{array}{r} 50.5 - j9.36 \\ \underline{42.4 + j16.7} \end{array}$$

The remainder is $\quad 8.1 - j26.06$

$$\theta \text{ arc tan } \frac{-26.06}{8.1} = \text{arc tan } -3.217 = -72.7^\circ,$$

$$z = \frac{8.1}{\cos(-72.7^\circ)} = \frac{8.1}{.2957} = 27.1$$

In polar form the answer is $27.1\underline{/-72.7^\circ}$.

(2) Multiplication - To multiply two vectors in polar form, multiply the magnitudes together and add the angles:

MULTIPLY:

$$55\underline{/40^\circ} \text{ by } 47\underline{/55^\circ}$$

$$(55) \times (47) = 2585$$

$$40^\circ + 55^\circ = 95^\circ$$

hence $(55\underline{/40^\circ})\ (47\underline{/55^\circ}) = 2585\underline{/95^\circ}$

You can check this result by converting from polar to rectangular form, multiplying and then converting back to polar form.

$$55\underline{/40^\circ} = 42.13 + j35.35$$

$$47\underline{/55^\circ} = 26.96 + j38.5$$

Multiplying:

$$\begin{array}{l} 42.13 \ + j35.35 \\ \underline{26.96 \ + j38.5} \end{array}$$

$$\begin{array}{l} 1135.825 + j953.036 \\ \underline{\qquad\qquad\quad j1622.005 + j^2 1360.975} \end{array}$$

$$1135.825 + j2575.041 - 1360.975 =$$

The product is $-225.15 + j2575.04$

$$\theta = \text{arc tan } \frac{2575.04}{-225.15} = \text{arc tan } -11.43 = 95^\circ,$$

$$Z = \frac{-225.15}{\cos 95^\circ} = \frac{-225.15}{-.872} = 2582$$

The answer is $2582\underline{/95^\circ}$, practically the same as obtained before. Since a power of a quantity is a repeated multiplication process, note that $(15\underline{/20^\circ})^2 = 225\underline{/40^\circ}$, $(15\underline{/20^\circ})^3 = 3375\underline{/60^\circ}$, and so on. Raise the magnitude of the vector in polar form to the desired power and multiply the angle by the exponent.

(3) Division - To divide one vector by another, divide the magnitudes and subtract angles:

DIVIDE:

$$(55\angle 40^\circ) \text{ by } (47\angle 55^\circ)$$

$$55 \div 47 = 1.17$$

$$40^\circ - 55^\circ = -15^\circ$$

$$\text{hence } \frac{55\angle 40^\circ}{47\angle 55^\circ} = 1.17\angle -15^\circ$$

(4) To Extract a Root of a Vector - Conversely, to extract a root of a vector in polar form, extract the required root of the magnitude and divide the angle by the index of the root taken; e.g.:

$$\sqrt{10\angle 50^\circ} = 3.16\angle 25^\circ$$

$$\sqrt[3]{10\angle 50^\circ} = 2.15\angle 16.7^\circ$$

(5) Extracting a root or raising to a power - When either extracting a root or raising to a power, convert rectangular quantities to polar form before finding the root or power. Addition and subtraction are easier in the rectangular form. Multiplication, division, raising to a power, and extracting a root are easier in the polar form.

GEOMETRY

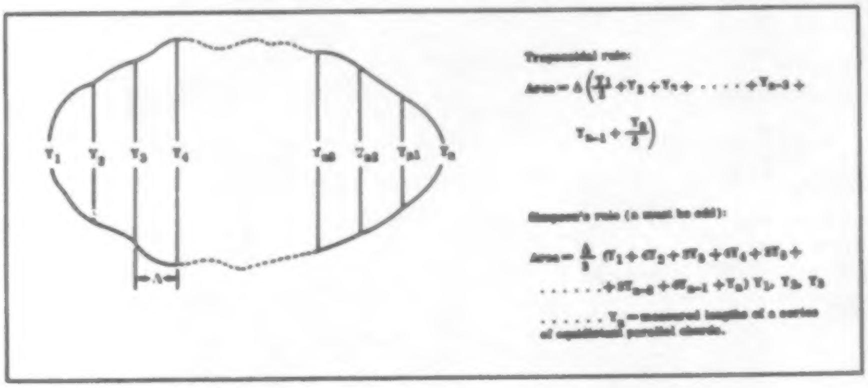
1. AREAS OF PLANE FIGURES - Figure 27 contains formulas used in resolving the area of plane figures.

2. AREAS OF IRREGULAR SURFACES - Figure 26 contains formulas used to resolve the area of irregular surfaces.

3. SURFACE AREA AND VOLUME OF SOLID FIGURES - Figure 28 contains formulas used to resolve the surface area and volume of solids.

TRIGONOMETRY

1. TRIGONOMETRIC FUNCTIONS - Several special relationships, called TRIGONOMETRIC FUNCTIONS, holds true in a right triangle. Electrical problems when reduced to a right triangle can be easily and quickly solved by the use of tables based upon these functions.



Trapezoidal rule:

$$\text{Area} = \Delta\left(\frac{Y_1}{2} + Y_2 + Y_3 + \cdots + Y_{n-2} + Y_{n-1} + \frac{Y_n}{2}\right)$$

Simpson's rule (n must be odd):

$$\text{Area} = \frac{\Delta}{3}(Y_1 + 4Y_2 + 2Y_3 + 4Y_4 + 2Y_5 + \cdots + 2Y_{n-2} + 4Y_{n-1} + Y_n)$$

$Y_1, Y_2, Y_3 \ldots\ldots Y_n$ = measured lengths of a series of equidistant parallel chords.

Figure 26. Areas of Irregular Plane Surfaces

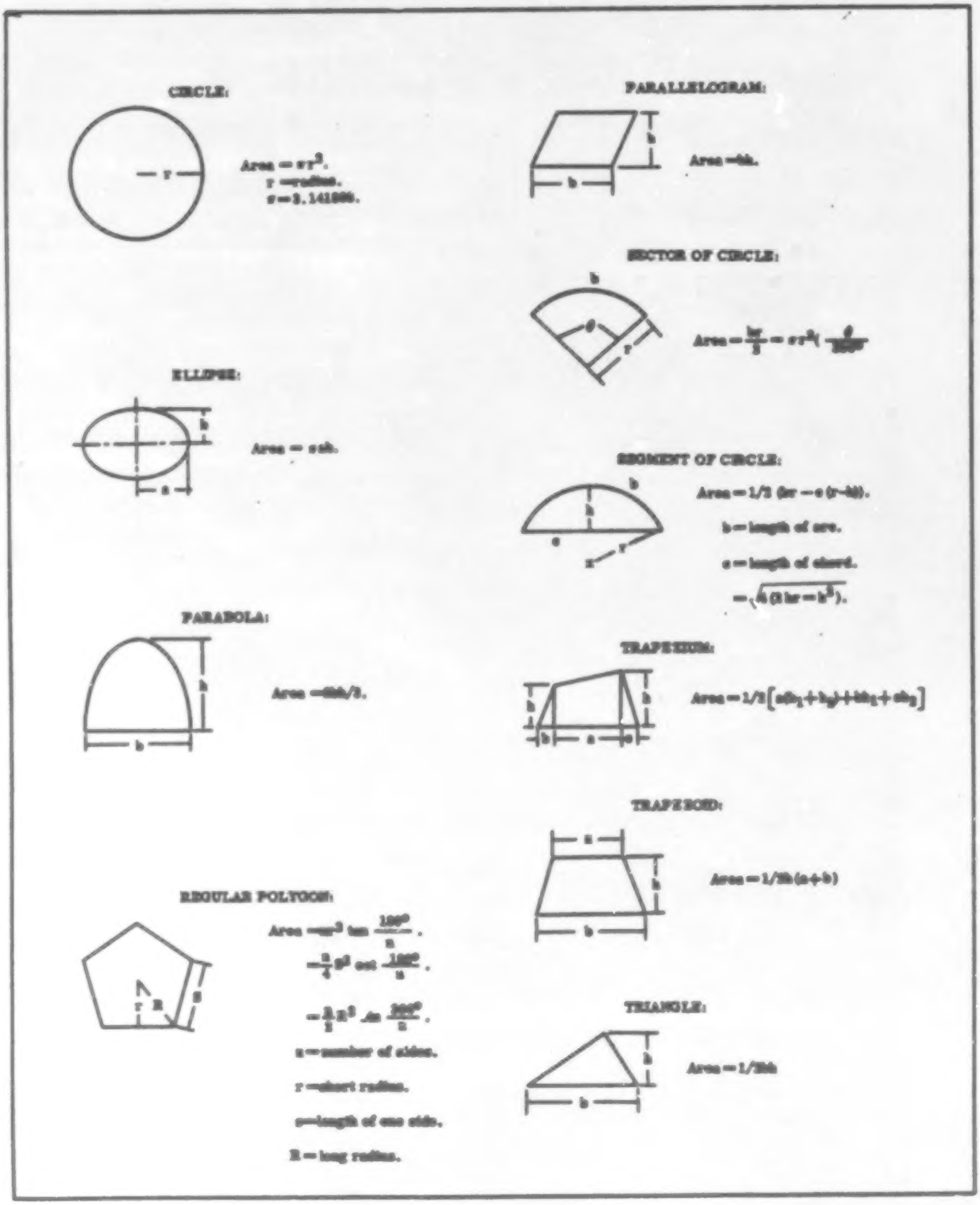
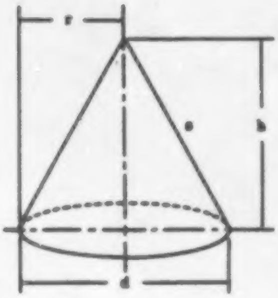


Figure 27. Areas of Plane Figures

**CONE WITH CIRCULAR BASE:**



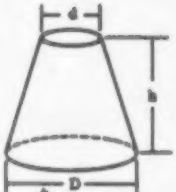
Conical area $= \pi r s = \pi r \sqrt{r^2 + h^2}$

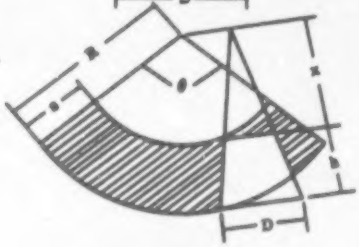
Volume $= \frac{\pi r^2 h}{3} = 1.047 r^2 h$

$= 0.2618 d^2 h$

s = slant height.

**CONIC FRUSTRUM:**





Volume $= \frac{\pi h}{3} (R^2 + Rr + r^2)$

$= \frac{\pi h}{3} \left( \frac{R^3 - r^3}{R - r} \right)$

$= \frac{\pi h}{12} (D^2 + Dd + d^2)$

$= \frac{h}{3} (a + A + \sqrt{aA})$

Area $= \frac{\pi s}{2} (D + d)$

$C = s + \frac{sd}{D - d} = s \left( 1 + \frac{d}{D - d} \right)$

$\theta = \frac{180D}{C} = \frac{180(D - d)}{s}$

A = area of base.

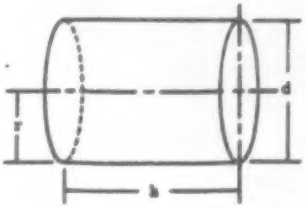
a = area of top.

R = D/2.

r = d/2.

s = slant height of frustrum.

**CYLINDER:**



Cylindrical surface $= \pi d h = 3.1416\ dh$

Total surface $= 2\pi r (r + h)$

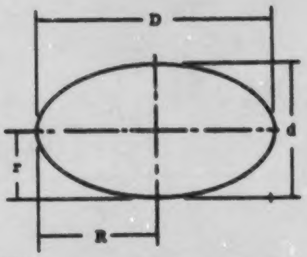
Volume $= \pi r^2 h = 0.7854 d^2 h$

$= \frac{c^2 h}{4\pi} = 0.0796\ c^2 h$

c = circumference.

Figure 28. Surface Areas and Volume of Solid Figures

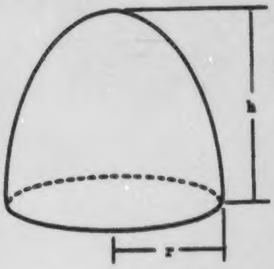
Figure 28. Surface Areas and Volume of Solid Figures (Contd)



**ELLIPSIOD:**

$$\text{Volume} = \frac{4\pi Rr^2}{3} = 4.1888\,Rr^2$$

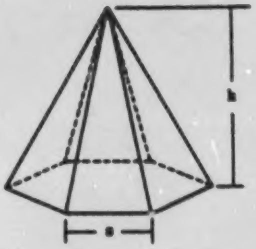
$$= 0.063\pi^2\,Dd^2 = 0.5231\,Dd^2$$



**PARABOLOID:**

$$\text{Volume} = \frac{\pi r^2 h}{2} = 1.5707\,r^2h$$

$$\text{Curved surface} = 0.5236\,\frac{r}{h^2}\left[(r^2+4h^2)^{3/2} - r^3\right]$$



**PYRAMID:**

$$\text{Volume} = \frac{Ah}{3}$$

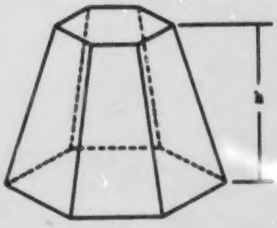
$$= \frac{h}{3}\left[nr^2\left(\tan\frac{180°}{n}\right)\right]$$

$$= \frac{h}{3}\left[\frac{ns^2}{4}\left(\cot\frac{360°}{2n}\right)\right]$$

A = area of base.

n = number of sides.

r = short radius of base.

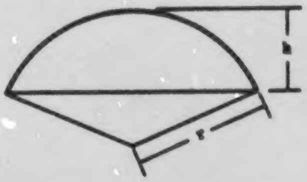


**PYRAMIDIC FRUSTRUM:**

$$\text{Volume} = \frac{h}{3}(a + A + \sqrt{aA})$$

A = area of base.

a = area of top.



**SECTOR OF SPHERE:**

$$\text{Total surface} = \frac{\pi r}{2}(4h + c)$$

$$\text{Volume} = \frac{2\pi r^2 h}{3} = 2.0944\,r^2h$$

$$= \frac{2\pi r^2}{3}\left(r - \sqrt{r^2 - \frac{c^2}{4}}\right)$$

$$c = \sqrt{4(2hr - h^2)}.$$

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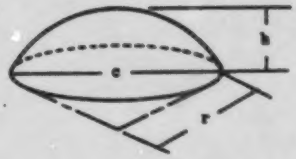
Figure 28. Surface Areas and Volume of Solid Figures (Contd)

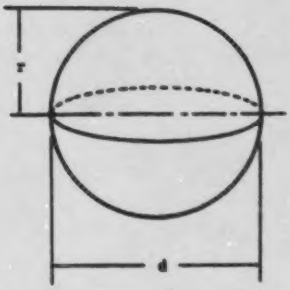


**SEGMENT OF SPHERE:**

$$\text{Spherical surface} = 2\pi rh = \frac{\pi}{4}(c^2+4h^2)$$

$$\text{Volume} = \pi h^2\left(r-\frac{h}{3}\right)$$

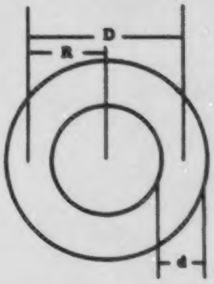
$$= \pi h^2\left(\frac{c^2+4h^2}{8h}-\frac{h}{3}\right)$$



**SPHERE:**

$$\text{Surface} = 4\pi r^2 = 12.5664\ r^2 = \pi d^2$$

$$\text{Volume} = \frac{4\pi r^3}{3} = 4.1888\ r^3$$



**TORUS OR RING OF CIRCULAR CROSS-SECTION:**

$$\text{Surface} = 4\pi^2\ Rr = 39.4784\ R_r$$

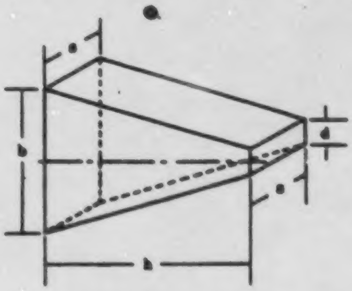
$$= 9.8696\ Dd$$

$$\text{Volume} = 2\pi^2\ Rr^2 = 19.74\ Rr^2$$

$$= 2.463\ Dd^2$$

D = 2 R = diameter to centers of cross section of material.

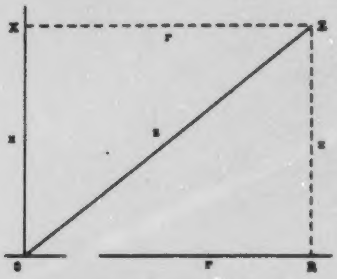
r = d/2.



**WEDGE FRUSTRUM:**

$$\text{Volume} = \frac{ha}{2}(a+b)$$

h = height between parallel bases.



Sine of θ (written sin θ) = $\frac{x}{z}$

Cosine of θ (written cos θ) = $\frac{r}{z}$

Tangent of θ (written tan θ) = $\frac{x}{r}$

Cotangent of θ (written cot θ) = $\frac{r}{x}$

Secant of θ (written sec θ) = $\frac{z}{r}$

Cosecant of θ (written csc θ) = $\frac{z}{x}$

Figure 29. Trigonometric Ratios

a. RATIOS - In Figure 29, θ is the angle ZOR, OR is the projection of OZ on the horizontal axis, OX is the projection of OZ on the vertical axis. The letters r, x, and z represent the lengths of OR, OX and OZ respectively. There are, in all, six different ratios between the sides r, x, and z. They are called trigonometric ratios or TRIGONOMETRIC FUNCTIONS.

b. FUNCTIONS - Generally you will use the first three, sin θ, cos θ, and tan θ, in your work. You can save much time by memorizing them. Notice that three of the functions, csc θ, sec θ, and cot θ, are the reciprocals of sin θ, cos θ, and sec θ, respectively. If you suppose that Figure 29, θZ has a unit length of 1 and is rotated in a counterclockwise direction beginning with angle θ at 0° value and continuing until it is 90°, then the functions will vary within the following limits.

sin θ increases from 0 to 1.0
cos θ decreases from 1.0 to 0
tan θ increases from 0 to ∞
cot θ decreases from ∞ to 0
sec θ increases from 1.0 to ∞
csc θ decreases from ∞ to 1.0

c. QUADRANTS:

(1) When θ varies between the values of 90° and 180° (second quadrant), the projection r is negative and the functions which involve r become negative. Thus, cos θ and tan θ are negative in this quadrant. In the third quadrant, both r and x are negative. Therefore, sin θ and cos θ which involve only one or the other are negative, while tan θ, which involves both r and x, is positive. In the fourth quadrant, r is positive, but x is still negative. For this reason, sin θ and tan θ are negative in the fourth quadrant, while cos θ is positive (Figure 30).

(2) Trigonometric tables give functions up to 90° only. Therefore, you will have special rules for angles in other quadrants. The following rules apply for functions of angles greater than 90°.

(a) IN QUADRANT II:

θ = 90° + some angle which is designated a (alpha)

sin (90° + a) = sin (90° - a)
cos (90° + a) = -cos (90° - a)
tan (90° + a) = -tan (90° - a)

(b) IN QUADRANT III:

θ = 180° + a

sin (180° + a) = -sin a
cos (180° + a) = -cos a
tan (180° + a) = tan a

| Quadrant | | Sin θ From | To | Cos θ From | To | Tan θ From | To |
|---|---|---|---|---|---|---|---|
| I | (0°-90°) | 0 | 1.0 | 1.0 | 0 | 0 | |
| II | (90°-180°) | 1.0 | 0 | 0 | 1.0 | ∞ | 0 |
| III | (180°-270°) | 0 | -1.0 | -1.0 | 0 | 0 | ∞ |
| IV | (270°-360°) | -1.0 | 0 | 0 | 1.0 | ∞ | 0 |

Figure 30. Variations in Values of Functions

(c) IN QUADRANT IV:

$$\theta = 270° + a$$

$$\sin (270° + a) = -\sin (90° - a)$$

$$\cos (270° + a) = \cos (90° - a)$$

$$\tan (270° + a) = \tan (90° - a)$$

(d) EXAMPLES:

1. FIND sin 39°

Solution: Find the angle 29° in the table. Opposite this angle and under the heading sine is 0.4848.

Therefore $\sin 29° = 0.4848$.

2. FIND cos 129°

Solution: $\text{Cos } 120 = \cos (90° + 39°)$.

According to the rules for angles larger than 90°:

$$\cos (90° + 39°) = -\cos (90° - 39°) \text{ or } -\cos 51°$$

The tables show that $\cos 51°$ is 0.6293.

Therefore:

$$\cos 129° = -0.6293.$$

d. INTERPOLATION - Interpolation is necessary only occasionally since the tables give functions of angles to tenths of a degree.

e. INVERSE FUNCTION - The angle corresponding to a given function is called the INVERSE FUNCTION and is written arc sin θ or $\sin^{-1} \theta$. There are 2 angles corresponding to any given function. For example: arc sin 0.6428 is 40° or 140°. To avoid confusion, certain values of arc sin, arc cos, etc., are designated the principal values and are indicated by capitalizing the letter A of arc. The principal values of arc sin θ and arc tan θ are those in the first and fourth quadrants, and the principal values of arc cos θ are those in the first and second quadrants. Therefore,

$$\text{Arc } \sin 0.6428 = 40°$$

In finding the function of an angle, or vice versa, note that the functions repeat themselves every 360°. Thus,

$$\sin 400° = \sin (400° - 360°) = \sin 40° = 0.6428$$

You can say that a negative angle is equivalent to a positive angle which is 360° plus the negative angle. To illustrate,

$$-50° = 360° + (-50°) = 310°$$

Hence $\sin (-50°) = \sin 310° = -0.7660$.

Angles in the fourth quadrant are frequently expressed as negative angles.

### 3. SIMPLE RELATIONSHIPS:

$$\sin^2\theta + \cos^2\theta = 1$$

$$\tan\theta = \sin\theta/\cos\theta$$

$$\cot\theta = \cos\theta/\sin\theta$$

$$1 + \tan^2\theta = \sec^2\theta = 1/\cos^2\theta$$

$$1 + \cot^2\theta = \mathrm{cosec}^2\theta = 1/\sin^2\theta$$

$$\sin\theta = \sqrt{1-\cos^2\theta} = \frac{\tan\theta}{\sqrt{1+\tan^2\theta}} = \frac{1}{\sqrt{1+\cot^2\theta}}$$

$$\cos\theta = \sqrt{1-\sin^2\theta} = \frac{1}{\sqrt{1+\tan^2\theta}} = \frac{\cot\theta}{\sqrt{1+\cot^2\theta}}$$

$\sin(-\theta) = -\sin\theta$
$\cos(-\theta) = \cos\theta$
$\tan(-\theta) = -\tan\theta$
$\sin 2\theta = 2\sin\theta\cos\theta$

$$\cos 2\theta = \cos^2\theta - \sin^2\theta$$

$$= 1 - 2\sin^2\theta$$

$$= 2\cos^2\theta - 1$$

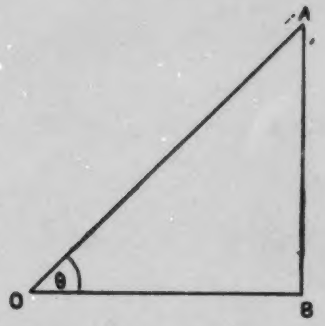
$$\tan 2\theta = \frac{2\tan\theta}{1-\tan^2\theta}$$

$\sin(A + B) = \sin A\cos B + \cos A\sin B$
$\cos(A + B)\ 1\ \cos A\cos B - \sin A\sin B$

$$\tan(A + B) = \frac{\tan A + \tan B}{1 - \tan A\tan B}$$

$\sin(A - B) = \sin A\cos B - \cos A\sin B$
$\cos(A - B)\ 1\ \cos A\cos B + \sin A\sin B$

$$\tan(A - B) = \frac{\tan A - \tan B}{1 + \tan A\tan B}$$



### DEGREES AND DECIMAL FRACTIONS TO RADIANS

To convert 25.78° into radians, find the equivalents of 20°, 5°, 0°.7, 0°.08 and add.

| Deg | Radians |
|---|---|
| 10 | 0.174533 |
| 20 | 0.349066 |
| 30 | 0.523599 |
| 40 | 0.698132 |
| 50 | 0.872665 |
| 60 | 1.047198 |
| 70 | 1.221731 |
| 80 | 1.396264 |
| 90 | 1.570797 |

| Radians | Degrees |
|---|---|
| 1 | 57.2958 |
| 2 | 114.5916 |
| 3 | 171.8873 |
| 4 | 229.1831 |
| 5 | 286.4789 |
| 6 | 343.7747 |
| 7 | 401.0705 |
| 8 | 458.3662 |
| 9 | 515.6620 |
| 10 | 572.9578 |

**Multiples and Fractions of π Radians**

| Radians | Radians | Degrees |
|---|---|---|
| π | 3.1416 | 180 |
| 2 π | 6.2832 | 360 |
| 3 π | 9.4248 | 540 |
| 4 π | 12.5664 | 720 |
| 5 π | 15.7080 | 900 |
| 6 π | 18.8496 | 1080 |
| 7 π | 21.9911 | 1260 |
| 8 π | 25.1327 | 1440 |
| 9 π | 28.2743 | 1620 |
| 10 π | 31.4159 | 1800 |

| deg | sin | cos | tan | cot |  | deg | sin | cos | tan | cot |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | .00000 | 1.0000 | .00000 |  | 90.0 | 6.0 | .10453 | 0.9945 | .10510 | 9.514 | 84.0 |
| .1 | .00175 | 1.0000 | .00175 | 573.0 | .9 | .1 | .10626 | .9943 | .10687 | 9.357 | .9 |
| .2 | .00349 | 1.0000 | .00349 | 286.5 | .8 | .2 | .10800 | .9942 | .10863 | 9.205 | .8 |
| .3 | .00524 | 1.0000 | .00524 | 191.0 | .7 | .3 | .10973 | .9940 | .11040 | 9.058 | .7 |
| .4 | .00698 | 1.0000 | .00698 | 143.24 | .6 | .4 | .11147 | .9938 | .11217 | 8.915 | .6 |
| .5 | .00873 | 1.0000 | .00873 | 114.59 | .5 | .5 | .11320 | .9936 | .11394 | 8.777 | .5 |
| .6 | .01047 | 0.9999 | .10147 | 95.49 | .4 | .6 | .11494 | .9934 | .11570 | 8.643 | .4 |
| .7 | .01222 | .9999 | .01222 | 81.85 | .3 | .7 | .11667 | .9932 | .11747 | 8.513 | .3 |
| .8 | .01396 | .9999 | .01396 | 71.62 | .2 | .8 | .11840 | .9930 | .11924 | 8.386 | .2 |
| .9 | .01571 | .9999 | .01571 | 63.66 | .1 | .9 | .12014 | .9928 | .12101 | 8.264 | .1 |
| 1.0 | .01745 | 0.9998 | .01746 | 57.29 | 89.0 | 7.0 | .12187 | 0.9925 | .12278 | 8.144 | 83.0 |
| .1 | .01920 | .9998 | .01920 | 52.08 | .9 | .1 | .12360 | .9923 | .12456 | 8.028 | .9 |
| .2 | .02094 | .9998 | .02095 | 47.74 | .8 | .2 | .12533 | .9921 | .12633 | 7.916 | .8 |
| .3 | .02269 | .9997 | .02269 | 44.07 | .7 | .3 | .12706 | .9919 | .12810 | 7.806 | .7 |
| .4 | .02443 | .9997 | .02444 | 40.92 | .6 | .4 | .12880 | .9917 | .12988 | 7.700 | .6 |
| .5 | .02618 | .9997 | .02619 | 38.19 | .5 | .5 | .13053 | .9914 | .13165 | 7.596 | .5 |
| .6 | .02792 | .9996 | .02793 | 35.80 | .4 | .6 | .13226 | .9912 | .13343 | 7.495 | .4 |
| .7 | .02967 | .9996 | .02968 | 33.69 | .3 | .7 | .13399 | .9910 | .13521 | 7.396 | .3 |
| .8 | .03141 | .9995 | .03143 | 31.82 | .2 | .8 | .13572 | .9907 | .13698 | 7.300 | .2 |
| .9 | .03316 | .9995 | .03317 | 30.14 | .1 | .9 | .13744 | .9905 | .13876 | 7.207 | .1 |
| 2.0 | .03490 | 0.9994 | .03492 | 28.64 | 88.0 | 8.0 | .13917 | 0.9903 | .14054 | 7.115 | 82.0 |
| .1 | .03664 | .9993 | .03667 | 27.27 | .9 | .1 | .14090 | .9900 | .14232 | 7.026 | .9 |
| .2 | .03839 | .9993 | .03842 | 26.03 | .8 | .2 | .14263 | .9898 | .14410 | 6.940 | .8 |
| .3 | .04013 | .9992 | .04016 | 24.90 | .7 | .3 | .14436 | .9895 | .14588 | 6.855 | .7 |
| .4 | .04188 | .9991 | .04191 | 23.86 | .6 | .4 | .14608 | .9893 | .14767 | 6.772 | .6 |
| .5 | .04362 | .9990 | .04366 | 22.90 | .5 | .5 | .14781 | .9890 | .14945 | 6.691 | .5 |
| .6 | .04536 | .9990 | .04541 | 22.02 | .4 | .6 | .14954 | .9888 | .15124 | 6.612 | .4 |
| .7 | .04711 | .9989 | .04716 | 21.20 | .3 | .7 | .15126 | .9885 | .15302 | 6.535 | .3 |
| .8 | .04885 | .9988 | .04891 | 20.45 | .2 | .8 | .15299 | .9882 | .15481 | 6.460 | .2 |
| .9 | .05059 | .9987 | .05066 | 19.74 | .1 | .9 | .15471 | .9880 | .15660 | 6.386 | .1 |
| 3.0 | .05234 | 0.9986 | .05241 | 19.081 | 87.0 | 9.0 | .15643 | 0.9877 | .15838 | 6.314 | 81.0 |
| .1 | .05408 | .9985 | .05416 | 18.464 | .9 | .1 | .15816 | .9874 | .16017 | 6.243 | .9 |
| .2 | .05582 | .9984 | .05591 | 17.886 | .8 | .2 | .15988 | .9871 | .16196 | 6.174 | .8 |
| .3 | .05756 | .9983 | .05766 | 17.343 | .7 | .3 | .16160 | .9869 | .16376 | 6.107 | .7 |
| .4 | .05931 | .9982 | .05941 | 16.832 | .6 | .4 | .16333 | .9866 | .16555 | 6.041 | .6 |
| .5 | .06105 | .9981 | .06116 | 16.350 | .5 | .5 | .16505 | .9863 | .16734 | 5.976 | .5 |
| .6 | .06279 | .9980 | .06291 | 15.895 | .4 | .6 | .16677 | .9860 | .16914 | 5.912 | .4 |
| .7 | .06453 | .9979 | .06467 | 15.464 | .3 | .7 | .16849 | .9857 | .17093 | 5.850 | .3 |
| .8 | .06627 | .9978 | .06642 | 15.056 | .2 | .8 | .17021 | .9854 | .17273 | 5.789 | .2 |
| .9 | .06802 | .9977 | .06817 | 14.669 | .1 | .9 | .17193 | .9851 | .17453 | 5.730 | .1 |
| 4.0 | .06976 | 0.9976 | .06993 | 14.301 | 86.0 | 10.0 | .1736 | 0.9848 | .1763 | 5.671 | 80.0 |
| .1 | .07150 | .9974 | .07168 | 13.951 | .9 | .1 | .1754 | .9845 | .1781 | 5.614 | .9 |
| .2 | .07324 | .9973 | .07344 | 13.617 | .8 | .2 | .1771 | .9842 | .1799 | 5.558 | .8 |
| .3 | .07498 | .9972 | .17519 | 13.300 | .7 | .3 | .1788 | .9839 | .1817 | 5.503 | .7 |
| .4 | .07672 | .9971 | .07695 | 12.996 | .6 | .4 | .1805 | .9836 | .1835 | 5.449 | .6 |
| .5 | .07846 | .9969 | .07870 | 12.706 | .5 | .5 | .1822 | .9833 | .1853 | 5.396 | .5 |
| .6 | .08020 | .9968 | .08046 | 12.429 | .4 | .6 | .1840 | .9829 | .1871 | 5.343 | .4 |
| .7 | .08194 | .9966 | .08221 | 12.163 | .3 | .7 | .1857 | .9826 | .1890 | 5.292 | .3 |
| .8 | .08368 | .9965 | .08397 | 11.909 | .2 | .8 | .1874 | .9823 | .1908 | 5.242 | .2 |
| .9 | .08542 | .9963 | .08573 | 11.664 | .1 | .9 | .1891 | .9820 | .1926 | 5.193 | .1 |
| 5.0 | .08716 | 0.9962 | .08749 | 11.430 | 85.0 | 11.0 | .1908 | 0.9816 | .1944 | 5.145 | 79.0 |
| .1 | .08889 | .9960 | .08925 | 11.205 | .9 | .1 | .1925 | .9813 | .1962 | 5.097 | .9 |
| .2 | .09063 | .9959 | .09101 | 10.988 | .8 | .2 | .1942 | .9810 | .1980 | 5.050 | .8 |
| .3 | .09237 | .9957 | .09277 | 10.780 | .7 | .3 | .1959 | .9806 | .1998 | 5.005 | .7 |
| .4 | .09411 | .9956 | .09453 | 10.579 | .6 | .4 | .1977 | .9803 | .2016 | 4.959 | .6 |
| .5 | .09585 | .9954 | .09629 | 10.385 | .5 | .5 | .1994 | .9799 | .2035 | 4.915 | .5 |
| .6 | .09758 | .9952 | .09805 | 10.199 | .4 | .6 | .2011 | .9796 | .2053 | 4.872 | .4 |
| .7 | .09932 | .9951 | .09981 | 10.019 | .3 | .7 | .2028 | .9792 | .2071 | 4.829 | .3 |
| .8 | .10106 | .9949 | .10158 | 9.845 | .2 | .8 | .2045 | .9789 | .2089 | 4.787 | .2 |
| .9 | .10279 | .9947 | .10334 | 9.677 | .1 | .9 | .2062 | .9785 | .2107 | 4.745 | .1 |
|  | cos | sin | cot | tan | deg |  | cos | sin | cot | tan | deg |

Figure 31. Natural Trigonometric Functions for Decimal Fractions of a Degree

Figure 31 (Cont'd)

Natural Trigonometric Functions for Decimal Fractions of a Degree

| deg | sin | cos | tan | cot | | deg | sin | cos | tan | cot | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.0 | 0.2079 | 0.9781 | 0.2126 | 4.705 | 78.0 | 18.0 | 0.3090 | 0.9511 | 0.3249 | 3.078 | 72.0 |
| .1 | .2096 | .9778 | .2144 | 4.665 | .9 | .1 | .3107 | .9505 | .3269 | 3.060 | .9 |
| .2 | .2113 | .9774 | .2162 | 4.625 | .8 | .2 | .3123 | .9500 | .3288 | 3.042 | .8 |
| .3 | .2130 | .9770 | .2180 | 4.586 | .7 | .3 | .3140 | .9494 | .3307 | 3.024 | .7 |
| .4 | .2147 | .9767 | .2199 | 4.548 | .6 | .4 | .3156 | .9489 | .3327 | 3.006 | .6 |
| .5 | .2164 | .9763 | .2217 | 4.511 | .5 | .5 | .3173 | .9483 | .3346 | 2.989 | .5 |
| .6 | .2181 | .9759 | .2235 | 4.474 | .4 | .6 | .3190 | .9478 | .3365 | 2.971 | .4 |
| .7 | .2198 | .9755 | .2254 | 4.437 | .3 | .7 | .3206 | .9472 | .3385 | 2.954 | .3 |
| .8 | .2215 | .9751 | .2272 | 4.402 | .2 | .8 | .3223 | .9466 | .3404 | 2.937 | .2 |
| .9 | .2233 | .9748 | .2290 | 4.366 | .1 | .9 | .3239 | .9461 | .3424 | 2.921 | .1 |
| 13.0 | 0.2250 | 0.9744 | 0.2309 | 4.331 | 77.0 | 19.0 | 0.3256 | 0.9455 | 0.3443 | 2.904 | 71.0 |
| .1 | .2267 | .9740 | .2327 | 4.297 | .9 | .1 | .3272 | .9449 | .3463 | 2.888 | .9 |
| .2 | .2284 | .9736 | .2345 | 4.264 | .8 | .2 | .3289 | .9444 | .3482 | 2.872 | .8 |
| .3 | .2300 | .9732 | .2364 | 4.230 | .7 | .3 | .3305 | .9438 | .3502 | 2.856 | .7 |
| .4 | .2317 | .9728 | .2382 | 4.198 | .6 | .4 | .3322 | .9432 | .3522 | 2.840 | .6 |
| .5 | .2334 | .9724 | .2401 | 4.165 | .5 | .5 | .3338 | .9426 | .3541 | 2.824 | .5 |
| .6 | .2351 | .9720 | .2419 | 4.134 | .4 | .6 | .3355 | .9421 | .3561 | 2.808 | .4 |
| .7 | .2368 | .9715 | .2438 | 4.102 | .3 | .7 | .3371 | .9415 | .3581 | 2.793 | .3 |
| .8 | .2385 | .9711 | .2456 | 4.071 | .2 | .8 | .3387 | .9409 | .3600 | 2.778 | .2 |
| .9 | .2402 | .9707 | .2475 | 4.041 | .1 | .9 | .3404 | .9403 | .3620 | 2.762 | .1 |
| 14.0 | 0.2419 | 0.9703 | 0.2493 | 4.011 | 76.0 | 20.0 | 0.3420 | 0.9397 | 0.3640 | 2.747 | 70.0 |
| .1 | .2436 | .9699 | .2512 | 3.981 | .9 | .1 | .3437 | .9391 | .3659 | 2.733 | .9 |
| .2 | .2453 | .9694 | .2530 | 3.952 | .8 | .2 | .3453 | .9385 | .3679 | 2.718 | .8 |
| .3 | .2470 | .9690 | .2549 | 3.923 | .7 | .3 | .3469 | .9379 | .3699 | 2.703 | .7 |
| .4 | .2487 | .9686 | .2568 | 3.895 | .6 | .4 | .3486 | .9373 | .3719 | 2.689 | .6 |
| .5 | .2504 | .9681 | .2586 | 3.867 | .5 | .5 | .3502 | .9367 | .3739 | 2.675 | .5 |
| .6 | .2521 | .9677 | .2605 | 3.839 | .4 | .6 | .3518 | .9361 | .3759 | 2.660 | .4 |
| .7 | .2538 | .9673 | .2623 | 3.812 | .3 | .7 | .3535 | .9354 | .3779 | 2.646 | .3 |
| .8 | .2554 | .9668 | .2642 | 3.785 | .2 | .8 | .3551 | .9348 | .3799 | 2.633 | .2 |
| .9 | .2571 | .9664 | .2661 | 3.758 | .1 | .9 | .3567 | .9342 | .3819 | 2.619 | .1 |
| 15.0 | 0.2588 | 0.9659 | 0.2679 | 3.732 | 75.0 | 21.0 | 0.3584 | 0.9336 | 0.3839 | 2.605 | 69.0 |
| .1 | .2605 | .9655 | .2698 | 3.706 | .9 | .1 | .3600 | .9330 | .3859 | 2.592 | .9 |
| .2 | .2622 | .9650 | .2717 | 3.681 | .8 | .2 | .3616 | .9323 | .3879 | 2.578 | .8 |
| .3 | .2639 | .9646 | .2736 | 3.655 | .7 | .3 | .3633 | .9317 | .3899 | 2.565 | .7 |
| .4 | .2656 | .9641 | .2754 | 3.630 | .6 | .4 | .3649 | .9311 | .3919 | 2.552 | .6 |
| .5 | .2672 | .9636 | .2773 | 3.606 | .5 | .5 | .3665 | .9304 | .3939 | 2.539 | .5 |
| .6 | .2689 | .9632 | .2792 | 3.582 | .4 | .6 | .3681 | .9298 | .3959 | 2.526 | .4 |
| .7 | .2706 | .9627 | .2811 | 3.558 | .3 | .7 | .3697 | .9291 | .3979 | 2.513 | .3 |
| .8 | .2723 | .9622 | .2830 | 3.534 | .2 | .8 | .3714 | .9285 | .4000 | 2.500 | .2 |
| .9 | .2740 | .9617 | .2849 | 3.511 | .1 | .9 | .3730 | .9278 | .4020 | 2.488 | .1 |
| 16.0 | 0.2756 | 0.9613 | 0.2867 | 3.487 | 74.0 | 22.0 | 0.3746 | 0.9272 | 0.4040 | 2.475 | 68.0 |
| .1 | .2773 | .9608 | .2886 | 3.465 | .9 | .1 | .3762 | .9265 | .4061 | 2.463 | .9 |
| .2 | .2790 | .9603 | .2905 | 3.442 | .8 | .2 | .3778 | .9259 | .4081 | 2.450 | .8 |
| .3 | .2807 | .9598 | .2924 | 3.420 | .7 | .3 | .3795 | .9252 | .4101 | 2.438 | .7 |
| .4 | .2823 | .9593 | .2943 | 3.398 | .6 | .4 | .3811 | .9245 | .4122 | 2.426 | .6 |
| .5 | .2840 | .9588 | .2962 | 3.376 | .5 | .5 | .3827 | .9239 | .4142 | 2.414 | .5 |
| .6 | .2857 | .9583 | .2981 | 3.354 | .4 | .6 | .3843 | .9232 | .4163 | 2.402 | .4 |
| .7 | .2874 | .9578 | .3000 | 3.333 | .3 | .7 | .3859 | .9225 | .4183 | 2.391 | .3 |
| .8 | .2890 | .9573 | .3019 | 3.312 | .2 | .8 | .3875 | .9219 | .4204 | 2.379 | .2 |
| .9 | .2907 | .9568 | .3038 | 3.291 | .1 | .9 | .3891 | .9212 | .4224 | 2.367 | .1 |
| 17.0 | 0.2924 | 0.9563 | 0.3057 | 3.271 | 73.0 | 23.0 | 0.3907 | 0.9205 | 0.4245 | 2.356 | 67.0 |
| .1 | .2940 | .9558 | .3076 | 3.271 | .9 | .1 | .3923 | .9198 | .4265 | 2.344 | .9 |
| .2 | .2957 | .9553 | .3096 | 3.230 | .8 | .2 | .3939 | .9191 | .4286 | 2.333 | .8 |
| .3 | .2974 | .9548 | .3115 | 3.211 | .7 | .3 | .3955 | .9184 | .4307 | 2.322 | .7 |
| .4 | .2990 | .9542 | .3134 | 3.191 | .6 | .4 | .3971 | .9178 | .4327 | 2.311 | .6 |
| .5 | .3007 | .9537 | .3153 | 3.172 | .5 | .5 | .3987 | .9171 | .4348 | 2.300 | .5 |
| .6 | .3024 | .9532 | .3172 | 3.152 | .4 | .6 | .4003 | .9164 | .4369 | 2.289 | .4 |
| .7 | .3040 | .9527 | .3191 | 3.133 | .3 | .7 | .4019 | .9157 | .4390 | 2.278 | .3 |
| .8 | .3057 | .9521 | .3211 | 3.115 | .2 | .8 | .4035 | .9150 | .4411 | 2.267 | .2 |
| .9 | .3074 | .9516 | .3230 | 3.096 | .1 | .9 | .4051 | .9143 | .4431 | 2.257 | .1 |
| | cos | sin | cot | tan | deg | | cos | sin | cot | tan | deg |

Figure 31. (Contd)

Natural Trigonometric Functions for Decimal Fractions of a Degree

| deg | sin | cos | tan | cot | | deg | sin | cos | tan | cot | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 24.0 | 0.4067 | 0.9135 | 0.4452 | 2.246 | 66.0 | 30.0 | 0.5000 | 0.8660 | 0.5774 | 1.7321 | 60.0 |
| .1 | .4083 | .9128 | .4473 | 2.236 | .9 | .1 | .5015 | .8652 | .5797 | 1.7251 | .9 |
| .2 | .4099 | .9121 | .4494 | 2.225 | .8 | .2 | .5030 | .8643 | .5820 | 1.7182 | .8 |
| .3 | .4115 | .9114 | .4515 | 2.215 | .7 | .3 | .5045 | .8634 | .5844 | 1.7113 | .7 |
| .4 | .4131 | .9107 | .4536 | 2.204 | .6 | .4 | .5060 | .8625 | .5867 | 1.7045 | .6 |
| .5 | .4147 | .9100 | .4557 | 2.194 | .5 | .5 | .5075 | .8616 | .5890 | 1.6977 | .5 |
| .6 | .4163 | .9092 | .4578 | 2.184 | .4 | .6 | .5090 | .8607 | .5914 | 1.6909 | .4 |
| .7 | .4179 | .9085 | .4599 | 2.174 | .3 | .7 | .5105 | .8599 | .5938 | 1.6842 | .3 |
| .8 | .4195 | .9078 | .4621 | 2.164 | .2 | .8 | .5120 | .8590 | .5961 | 1.6775 | .2 |
| .9 | .4210 | .9070 | .4642 | 2.154 | .1 | .9 | .5135 | .8581 | .5985 | 1.6709 | .1 |
| 25.0 | 0.4226 | 0.9063 | 0.4663 | 2.145 | 65.0 | 31.0 | 0.5150 | 0.8572 | 0.6009 | 1.6643 | 59.0 |
| .1 | .4242 | .9056 | .4684 | 2.135 | .9 | .1 | .5165 | .8563 | .6032 | 1.6577 | .9 |
| .2 | .4258 | .9048 | .4706 | 2.125 | .8 | .2 | .5180 | .8554 | .6056 | 1.6512 | .8 |
| .3 | .4274 | .9041 | .4727 | 2.116 | .7 | .3 | .5195 | .8545 | .6080 | 1.6447 | .7 |
| .4 | .4289 | .9033 | .4748 | 2.106 | .6 | .4 | .5210 | .8536 | .6104 | 1.6383 | .6 |
| .5 | .4305 | .9026 | .4770 | 2.097 | .5 | .5 | .5225 | .8526 | .6128 | 1.6319 | .5 |
| .6 | .4321 | .9018 | .4791 | 2.087 | .4 | .6 | .5240 | .8517 | .6152 | 1.6255 | .4 |
| .7 | .4337 | .9011 | .4813 | 2.078 | .3 | .7 | .5255 | .8508 | .6176 | 1.6191 | .3 |
| .8 | .4352 | .9003 | .4834 | 2.069 | .2 | .8 | .5270 | .8499 | .6200 | 1.6128 | .2 |
| .9 | .4368 | .8996 | .4856 | 2.059 | .1 | .9 | .5284 | .8490 | .6224 | 1.6066 | .1 |
| 26.0 | 0.4384 | 0.8988 | 0.4877 | 2.050 | 64.0 | 32.0 | 0.5299 | 0.8480 | 0.6249 | 1.6003 | 58.0 |
| .1 | .4399 | .8980 | .4899 | 2.041 | .9 | .1 | .5314 | .8471 | .6273 | 1.5941 | .9 |
| .2 | .4415 | .8973 | .4921 | 2.032 | .8 | .2 | .5329 | .8462 | .6297 | 1.5880 | .8 |
| .3 | .4431 | .8965 | .4942 | 2.023 | .7 | .3 | .5344 | .8453 | .6322 | 1.5818 | .7 |
| .4 | .4446 | .8957 | .4964 | 2.014 | .6 | .4 | .5358 | .8443 | .6346 | 1.5757 | .6 |
| .5 | .4462 | .8949 | .4986 | 2.006 | .5 | .5 | .5373 | .8434 | .6371 | 1.5697 | .5 |
| .6 | .4478 | .8942 | .5008 | 1.997 | .4 | .6 | .5388 | .8425 | .6395 | 1.5637 | .4 |
| .7 | .4493 | .8934 | .5029 | 1.988 | .3 | .7 | .5402 | .8415 | .6420 | 1.5577 | .3 |
| .8 | .4509 | .8926 | .5051 | 1.980 | .2 | .8 | .5417 | .8406 | .6445 | 1.5517 | .2 |
| .9 | .4524 | .8918 | .5073 | 1.971 | .1 | .9 | .5432 | .8396 | .6469 | 1.5458 | .1 |
| 27.0 | 0.4540 | 0.8910 | 0.5095 | 1.963 | 63.0 | 33.0 | 0.5446 | 0.8387 | 0.6494 | 1.5399 | 57.0 |
| .1 | .4555 | .8902 | .5117 | 1.954 | .9 | .1 | .5461 | .8377 | .6519 | 1.5340 | .9 |
| .2 | .4571 | .8894 | .5139 | 1.946 | .8 | .2 | .5476 | .8368 | .6544 | 1.5282 | .8 |
| .3 | .4586 | .8886 | .5161 | 1.937 | .7 | .3 | .5490 | .8358 | .6569 | 1.5224 | .7 |
| .4 | .4602 | .8878 | .5184 | 1.929 | .6 | .4 | .5505 | .8348 | .6594 | 1.5166 | .6 |
| .5 | .4617 | .8870 | .5206 | 1.921 | .5 | .5 | .5519 | .8339 | .6619 | 1.5108 | .5 |
| .6 | .4633 | .8862 | .5228 | 1.913 | .4 | .6 | .5534 | .8329 | .6644 | 1.5051 | .4 |
| .7 | .4648 | .8854 | .5250 | 1.905 | .3 | .7 | .5548 | .8320 | .6669 | 1.4994 | .3 |
| .8 | .4664 | .8846 | .5272 | 1.897 | .2 | .8 | .5563 | .8310 | .6694 | 1.4938 | .2 |
| .9 | .4679 | .8838 | .5295 | 1.889 | .1 | .9 | .5577 | .8300 | .6720 | 1.4882 | .1 |
| 28.0 | 0.4695 | 0.8829 | 0.5317 | 1.881 | 62.0 | 34.0 | 0.5592 | 0.8290 | 0.6745 | 1.4826 | 56.0 |
| .1 | .4710 | .8821 | .5340 | 1.873 | .9 | .1 | .5606 | .8281 | .6771 | 1.4770 | .9 |
| .2 | .4726 | .8813 | .5362 | 1.865 | .8 | .2 | .5621 | .8271 | .6796 | 1.4715 | .8 |
| .3 | .4741 | .8805 | .5384 | 1.857 | .7 | .3 | .5635 | .8261 | .6822 | 1.4659 | .7 |
| .4 | .4756 | .8796 | .5407 | 1.849 | .6 | .4 | .5650 | .8251 | .6847 | 1.4605 | .6 |
| .5 | .4772 | .8788 | .5430 | 1.842 | .5 | .5 | .5664 | .8241 | .6873 | 1.4550 | .5 |
| .6 | .4787 | .8780 | .5452 | 1.834 | .4 | .6 | .5678 | .8231 | .6899 | 1.4496 | .4 |
| .7 | .4802 | .8771 | .5475 | 1.827 | .3 | .7 | .5693 | .8221 | .6924 | 1.4442 | .3 |
| .8 | .4818 | .8763 | .5498 | 1.819 | .2 | .8 | .5707 | .8211 | .6950 | 1.4388 | .2 |
| .9 | .4833 | .8755 | .5520 | 1.811 | .1 | .9 | .5721 | .8202 | .6976 | 1.4335 | .1 |
| 29.0 | 0.4848 | 0.8746 | 0.5543 | 1.804 | 61.0 | 35.0 | 0.5736 | 0.8192 | 0.7002 | 1.4281 | 55.0 |
| .1 | .4863 | .8738 | .5566 | 1.797 | .9 | .1 | .5750 | .8181 | .7028 | 1.4229 | .9 |
| .2 | .4879 | .8729 | .5589 | 1.789 | .8 | .2 | .5764 | .8171 | .7054 | 1.4176 | .8 |
| .3 | .4894 | .8721 | .5612 | 1.782 | .7 | .3 | .5779 | .8161 | .7080 | 1.4124 | .7 |
| .4 | .4909 | .8712 | .5635 | 1.775 | .6 | .4 | .5793 | .8151 | .7107 | 1.4071 | .6 |
| .5 | .4924 | .8704 | .5658 | 1.767 | .5 | .5 | .5807 | .8141 | .7133 | 1.4019 | .5 |
| .6 | .4939 | .8695 | .5681 | 1.760 | .4 | .6 | .5821 | .8131 | .7159 | 1.3968 | .4 |
| .7 | .4955 | .8686 | .5704 | 1.753 | .3 | .7 | .5835 | .8121 | .7186 | 1.3916 | .3 |
| .8 | .4970 | .8678 | .5727 | 1.746 | .2 | .8 | .5850 | .8111 | .7212 | 1.3865 | .2 |
| .9 | .4985 | .8669 | .5750 | 1.739 | .1 | .9 | .5864 | .8100 | .7239 | 1.3814 | .1 |
| | cos | sin | cot | tan | deg | | cos | sin | cot | tan | deg |

Figure 31. (Contd)

Natural Trigonometric Functions for Decimal Fractions of a Degree

| deg | sin | cos | tan | cot | | deg | sin | cos | tan | cot | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 36.0 | 0.5878 | 0.8090 | 0.7265 | 1.3764 | 54.0 | 40.5 | 0.6494 | 0.7604 | 0.8541 | 1.1708 | 49.5 |
| .1 | .5892 | .8080 | .7292 | 1.3713 | .9 | .6 | .6508 | .7593 | .8571 | 1.1667 | .4 |
| .2 | .5906 | .8070 | .7319 | 1.3663 | .8 | .7 | .6521 | .7581 | .8601 | 1.1626 | .3 |
| .3 | .5920 | .8059 | .7346 | 1.3613 | .7 | .8 | .6534 | .7570 | .8632 | 1.1585 | .2 |
| .4 | .5934 | .8049 | .7373 | 1.3564 | .6 | .9 | .6547 | .7559 | .8662 | 1.1544 | .1 |
| .5 | .5948 | .8039 | .7400 | 1.3514 | .5 | 41.0 | 0.6561 | 0.7547 | 0.8693 | 1.1504 | 49.0 |
| .6 | .5962 | .8028 | .7427 | 1.3465 | .4 | .1 | .6574 | .7536 | .8724 | 1.1463 | .9 |
| .7 | .5976 | .8018 | .7454 | 1.3416 | .3 | .2 | .6587 | .7524 | .8754 | 1.1423 | .8 |
| .8 | .5990 | .8007 | .7481 | 1.3367 | .2 | .3 | .6600 | .7513 | .8785 | 1.1383 | .7 |
| .9 | .6004 | .7997 | .7508 | 1.3319 | .1 | .4 | .6613 | .7501 | .8816 | 1.1343 | .6 |
| 37.0 | 0.6018 | 0.7986 | 0.7536 | 1.3270 | 53.0 | .5 | .6626 | .7490 | .8847 | 1.1303 | .5 |
| .1 | .6032 | .7976 | .7563 | 1.3222 | .9 | .6 | .6639 | .7478 | .8878 | 1.1263 | .4 |
| .2 | .6046 | .7965 | .7590 | 1.3175 | .8 | .7 | .6652 | .7466 | .8910 | 1.1224 | .3 |
| .3 | .6060 | .7955 | .7618 | 1.3127 | .7 | .8 | .6665 | .7455 | .8941 | 1.1184 | .2 |
| .4 | .6074 | .7944 | .7646 | 1.3079 | .6 | .9 | .6678 | .7443 | .8972 | 1.1145 | .1 |
| .5 | .6088 | .7934 | .7673 | 1.3032 | .5 | 42.0 | 0.6691 | 0.7431 | 0.9004 | 1.1106 | 48.0 |
| .6 | .6101 | .7923 | .7701 | 1.2985 | .4 | .1 | .6704 | .7420 | .9036 | 1.1067 | .9 |
| .7 | .6115 | .7912 | .7729 | 1.2938 | .3 | .2 | .6717 | .7408 | .9067 | 1.1028 | .8 |
| .8 | .6129 | .7902 | .7757 | 1.2892 | .2 | .3 | .6730 | .7396 | .9099 | 1.0990 | .7 |
| .9 | .6143 | .7891 | .7785 | 1.2846 | .1 | .4 | .6743 | .7385 | .9131 | 1.0951 | .6 |
| 38.0 | 0.6157 | 0.7880 | 0.7813 | 1.2799 | 52.0 | .5 | .6756 | .7373 | .9163 | 1.0913 | .5 |
| .1 | .6170 | .7869 | .7841 | 1.2753 | .9 | .6 | .6769 | .7361 | .9195 | 1.0875 | .4 |
| .2 | .6184 | .7859 | .7869 | 1.2708 | .8 | .7 | .6782 | .7349 | .9228 | 1.0837 | .3 |
| .3 | .6198 | .7848 | .7898 | 1.2662 | .7 | .8 | .6794 | .7337 | .9260 | 1.0799 | .2 |
| .4 | .6211 | .7837 | .7926 | 1.2617 | .6 | .9 | .6807 | .7325 | .9293 | 1.0761 | .1 |
| .5 | .6225 | .7826 | .7954 | 1.2572 | .5 | 43.0 | 0.6820 | 0.7314 | 0.9325 | 1.0724 | 47.0 |
| .6 | .6239 | .7815 | .7983 | 1.2527 | .4 | .1 | .6833 | .7302 | .9358 | 1.0686 | .9 |
| .7 | .6252 | .7804 | .8012 | 1.2482 | .3 | .2 | .6845 | .7290 | .9391 | 1.0649 | .8 |
| .8 | .6266 | .7793 | .8040 | 1.2437 | .2 | .3 | .6858 | .7278 | .9424 | 1.0612 | .7 |
| .9 | .6280 | .7782 | .8069 | 1.2393 | .1 | .4 | .6871 | .7266 | .9457 | 1.0575 | .6 |
| 39.0 | 0.6293 | 0.7771 | 0.8098 | 1.2349 | 51.0 | .5 | .6884 | .7254 | .9490 | 1.0538 | .5 |
| .1 | .6307 | .7760 | .8127 | 1.2305 | .9 | .6 | .6896 | .7242 | .9523 | 1.0501 | .4 |
| .2 | .6320 | .7749 | .8156 | 1.2261 | .8 | .7 | .6909 | .7230 | .9556 | 1.0464 | .3 |
| .3 | .6334 | .7738 | .8185 | 1.2218 | .7 | .8 | .6921 | .7218 | .9590 | 1.0428 | .2 |
| .4 | .6347 | .7727 | .8214 | 1.2174 | .6 | .9 | .6934 | .7206 | .9623 | 1.0392 | .1 |
| .5 | .6361 | .7716 | .8243 | 1.2131 | .5 | 44.0 | 0.6947 | 0.7193 | 0.9657 | 1.0355 | 46.0 |
| .6 | .6374 | .7705 | .8273 | 1.2088 | .4 | .1 | .6959 | .7181 | .9691 | 1.0319 | .9 |
| .7 | .6388 | .7694 | .8302 | 1.2045 | .3 | .2 | .6972 | .7169 | .9725 | 1.0283 | .8 |
| .8 | .6401 | .7683 | .8332 | 1.2002 | .2 | .3 | .6984 | .7157 | .9759 | 1.0247 | .7 |
| .9 | .6414 | .7672 | .8361 | 1.1960 | .1 | .4 | .6997 | .7145 | .9793 | 1.0212 | .6 |
| 40.0 | 0.6428 | 0.7660 | 0.8391 | 1.1918 | 50.0 | .5 | .7009 | .7133 | .9827 | 1.0176 | .5 |
| .1 | .6441 | .7649 | .8421 | 1.1875 | .9 | .6 | .7022 | .7120 | .9861 | 1.0141 | .4 |
| .2 | .6455 | .7638 | .8451 | 1.1833 | .8 | .7 | .7034 | .7108 | .9896 | 1.0105 | .3 |
| .3 | .6468 | .7627 | .8481 | 1.1792 | .7 | .8 | .7046 | .7096 | .9930 | 1.0070 | .2 |
| .4 | .6481 | .7615 | .8511 | 1.1750 | .6 | .9 | .7059 | .7083 | .9965 | 1.0035 | .1 |
| 40.5 | 0.6494 | 0.7604 | 0.8541 | 1.1708 | 49.5 | 45.0 | 0.7071 | 0.7071 | 1.0000 | 1.0000 | 45.0 |
| | cos | sin | cot | tan | deg | | cos | sin | cot | tan | deg |

| ORIGINAL VALUE | DESIRED VALUE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | MEGA | KILO | UNITS | DECI | CENTI | MILLI | MICRO | MICROMICRO |
| Mega | | 3→ | 6→ | 7→ | 8→ | 9→ | 12→ | 18→ |
| Kilo | ←3 | | 3→ | 4→ | 5→ | 6→ | 9→ | 15→ |
| Units | ←6 | ←3 | | 1→ | 2→ | 3→ | 6→ | 12→ |
| Deci | ←7 | ←4 | ←1 | | 1→ | 2→ | 5→ | 11→ |
| Centi | ←8 | ←5 | ←2 | ←1 | | 1→ | 4→ | 10→ |
| Milli | ←9 | ←6 | ←3 | ←2 | ←1 | | 3→ | 9→ |
| Micro | ←12 | ←9 | ←6 | ←5 | ←4 | ←3 | | 6→ |
| Micromicro | ←18 | ←15 | ←12 | ←11 | ←10 | ←9 | ←6 | |

Figure 32. Metric Conversion Table

| MULTIPLES | PREFIXES | MULTIPLES | PREFIXES |
|---|---|---|---|
| $10^{12}$ | tera- | $10^{-1}$ | deci- |
| $10^{9}$ | giga- | $10^{-2}$ | centi- |
| $10^{6}$ | mega- | $10^{-3}$ | milli- |
| $10^{4}$ | myria- | $10^{-6}$ | micro- |
| $10^{3}$ | kilo- | $10^{-9}$ | nano- |
| $10^{2}$ | hekto- | $10^{-12}$ | pico- |
| 10 | deka- | | |

Figure 33. Metric Multiple-Prefix Table

STANDARD RESISTANCE VALUES

| ALL VALUES IN OHMS | | | | | IDENTICAL | | MEGOHMS | |
|---|---|---|---|---|---|---|---|---|
| 1.0 | 10 | 100 | 1,000 | 10,000 | 100,000 | 0.1 | 1.0 | 10.0 |
| 1.1 | 11 | 110 | 1,100 | 11,000 | 110,000 | 0.11 | 1.1 | 11.0 |
| 1.2 | 12 | 120 | 1,200 | 12,000 | 120,000 | 0.12 | 1.2 | 12.0 |
| 1.3 | 13 | 130 | 1,300 | 13,000 | 130,000 | 0.13 | 1.3 | 13.0 |
| 1.5 | 15 | 150 | 1,500 | 15,000 | 150,000 | 0.15 | 1.5 | 15.0 |
| 1.6 | 16 | 160 | 1,600 | 16,000 | 160,000 | 0.16 | 1.6 | 16.0 |
| 1.8 | 18 | 180 | 1,800 | 18,000 | 180,000 | 0.18 | 1.8 | 18.0 |
| 2.0 | 20 | 200 | 2,000 | 20,000 | 200,000 | 0.2 | 2.0 | 20.0 |
| 2.2 | 22 | 220 | 2,200 | 22,000 | 220,000 | 0.22 | 2.2 | 22.0 |
| 2.4 | 24 | 240 | 2,400 | 24,000 | 240,000 | 0.24 | 2.4 | |
| 2.7 | 27 | 270 | 2,700 | 27,000 | 270,000 | 0.27 | 2.7 | |
| 3.0 | 30 | 300 | 3,000 | 30,000 | 300,000 | 0.3 | 3.0 | |
| 3.3 | 33 | 330 | 3,300 | 33,000 | 330,000 | 0.33 | 3.3 | |
| 3.6 | 36 | 360 | 3,600 | 36,000 | 360,000 | 0.36 | 3.6 | |
| 3.9 | 39 | 390 | 3,900 | 39,000 | 390,000 | 0.39 | 3.9 | |
| 4.3 | 43 | 430 | 4,300 | 43,000 | 430,000 | 0.43 | 4.3 | |
| 4.7 | 47 | 470 | 4,700 | 47,000 | 470,000 | 0.47 | 4.7 | |
| 5.1 | 51 | 510 | 5,100 | 51,000 | 510,000 | 0.51 | 5.1 | |
| 5.6 | 56 | 560 | 5,600 | 56,000 | 560,000 | 0.56 | 5.6 | |
| 6.2 | 62 | 620 | 6,200 | 62,000 | 620,000 | 0.62 | 6.2 | |
| 6.8 | 68 | 680 | 6,800 | 68,000 | 680,000 | 0.68 | 6.8 | |
| 7.5 | 75 | 750 | 7,500 | 75,000 | 750,000 | 0.75 | 7.5 | |
| 8.2 | 82 | 820 | 8,200 | 82,000 | 820,000 | 0.82 | 8.2 | |
| 9.1 | 91 | 910 | 9,100 | 91,000 | 910,000 | 0.91 | 9.1 | |

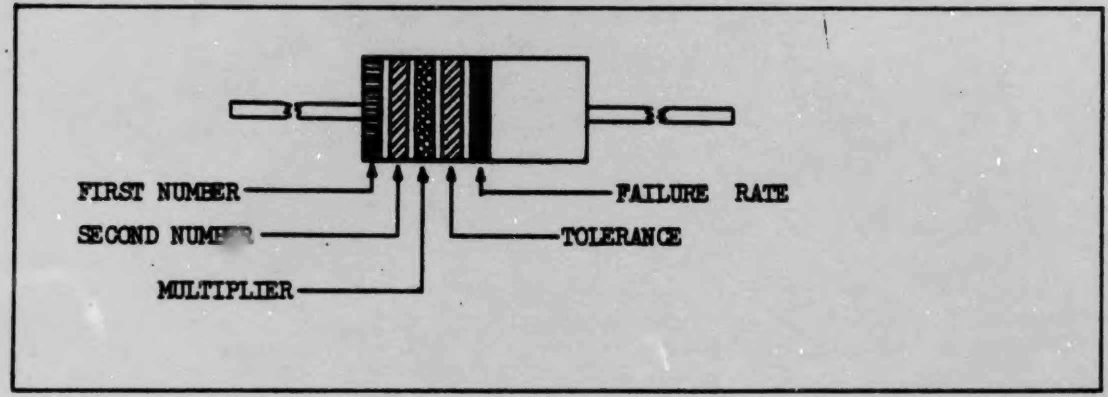
Figure 34. Standard Resistance Values

RESISTORS

| TOLERANCE | MULTIPLIER | SIGNIFICANT FIGURE | COLOR |
|---|---|---|---|
| | 1 | 0 | Black |
| | 10 | 1 | Brown |
| | 100 | 2 | Red |
| | 1,000 | 3 | Orange |
| | 10,000 | 4 | Yellow |
| | 100,000 | 5 | Green |
| | 1,000,000 | 6 | Blue |
| | 10,000,000 | 7 | Violet |
| | 100,000,000 | 8 | Gray |
| | 1,000,000,000 | 9 | White |
| 5 | 0.1 | | Gold |
| 10 | 0.01 | | Silver |
| 20 | | | No Color |

Figure 35. Resistor Multipliers

### COLOR CODE MARKING
### COMPOSITION-TYPE RESISTORS
### (MIL-STD)



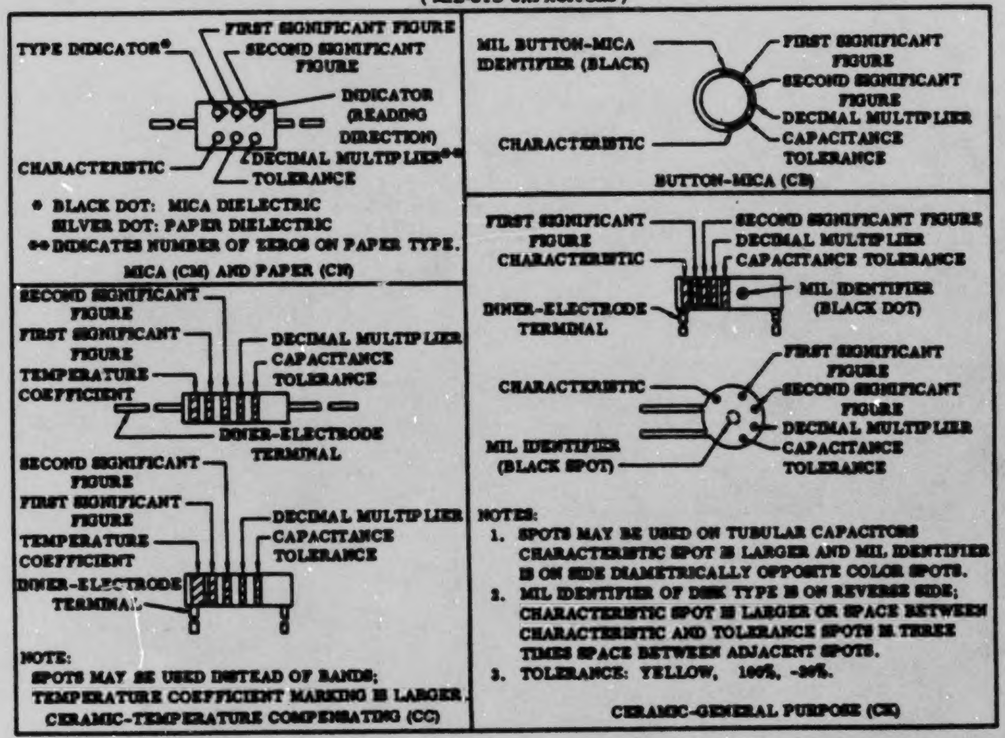
### COLOR CODES FOR
### PART IDENTIFICATION MARKING

| COLOR | PART | SIGNIFICANT FIGURES OF ELECTRICAL VALUE | | | TOLERANCE | FAILURE RATE PER 1000 HRS | |
|---|---|---|---|---|---|---|---|
| | | 1st Number | 2nd Number | Multiplier | | | |
| Black | Capacitor | 0 | 0 | 1 | ± 20% | L | 5 % |
| Brown | — | 1 | 1 | 10 | ± 1% | M | 1 % |
| Red | — | 2 | 2 | 100 | ± 2% | P | 0.1% |
| Orange | — | 3 | 3 | 1000 | — | R | 0.01% |
| Yellow | — | 4 | 4 | 10000 | — | S | 0.001% |
| Green | Diode | 5 | 5 | 100000 | — | T | 0.0001% |
| Blue | — | 6 | 6 | 1000000 | — | | |
| Violet | — | 7 | 7 | 10000000 | — | | |
| Gray | — | 8 | 8 | | — | | |
| White | — | 9 | 9 | | — | | |
| Gold | — | — | — | 0.1 | ± 5% | | |
| Silver | Coil | — | — | 0.01 | ± 10% | | |

Figure 36. Resistor Color Code

## CAPACITOR COLOR CODE MARKING

( MIL-STD CAPACITORS )



* BLACK DOT: MICA DIELECTRIC
SILVER DOT: PAPER DIELECTRIC
** INDICATES NUMBER OF ZEROS ON PAPER TYPE.

MICA (CM) AND PAPER (CN)

BUTTON-MICA (CB)

NOTE:
SPOTS MAY BE USED INSTEAD OF BANDS;
TEMPERATURE COEFFICIENT MARKING IS LARGER.

CERAMIC-TEMPERATURE COMPENSATING (CC)

NOTES:

1. SPOTS MAY BE USED ON TUBULAR CAPACITORS CHARACTERISTIC SPOT IS LARGER AND MIL IDENTIFIER IS ON SIDE DIAMETRICALLY OPPOSITE COLOR SPOTS.
2. MIL IDENTIFIER OF DISK TYPE IS ON REVERSE SIDE; CHARACTERISTIC SPOT IS LARGER OR SPACE BETWEEN CHARACTERISTIC AND TOLERANCE SPOTS IS THREE TIMES SPACE BETWEEN ADJACENT SPOTS.
3. TOLERANCE: YELLOW, 100%, -20%.

CERAMIC-GENERAL PURPOSE (CK)

### CAPACITOR COLOR CODE

| COLOR | SIG FIG. | MULTIPLIER | | CHARACTERISTIC[1] | | | | TOLERANCE[2] | | | | | TEMPERATURE COEFFICIENT (UUF/UF/°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | CC | | |
| | | DECIMAL | NUMBER OF ZEROS | CM | CN | CB | CK | CM | CN | CB | OVER 10UUF | 10UUF OR LESS | CC |
| BLACK | 0 | 1 | NONE | | A | | | 20 | 20 | 20 | 20 | 2 | ZERO |
| BROWN | 1 | 10 | 1 | B | E | B | W | | | | 1 | | -30 |
| RED | 2 | 100 | 2 | C | H | | X | 2 | | 2 | 2 | | -80 |
| ORANGE | 3 | 1,000 | 3 | D | J | D | | | 30 | | | | -150 |
| YELLOW | 4 | 10,000 | 4 | E | P | | | | | | | | -220 |
| GREEN | 5 | | 5 | F | R | | | | | | 5 | 0.5 | -330 |
| BLUE | 6 | | 6 | | S | | | | | | | | -470 |
| PURPLE (VIOLET) | 7 | | 7 | | T | W | | | | | | | -750 |
| GRAY | 8 | | 8 | | | X | | | | | | 0.25 | +30 |
| WHITE | 9 | | 9 | | | | | | | | 10 | 1 | -330 (±500)[3] |
| GOLD | | 0.1 | | | | | | 5 | | 5 | | | +100 |
| SILVER | | 0.01 | | | | | | 10 | 10 | 10 | | | |

[1] LETTERS ARE IN TYPE DESIGNATIONS GIVEN IN MIL-C SPECIFICATIONS.
[2] IN PERCENT, EXCEPT IN UUF FOR CC-TYPE CAPACITORS OF 10 UUF OR LESS.
[3] INTENDED FOR USE IN CIRCUITS NOT REQUIRING COMPENSATION.

Figure 37. Capacitor Color Code Marking

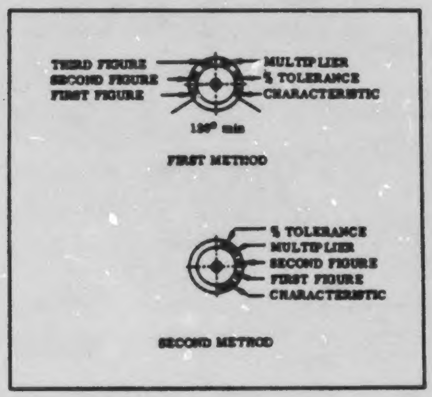


Figure 38. Button-Mica Capacitor Color Coding

CAPACITORS

| COLOR | MULTIPLIER RMA Mica and Ceramic-Dielectric | MULTIPLIER JAN Mica and Paper-Dielectric | MULTIPLIER JAN Ceramic Dielectric | VOLTAGE RATING | TEMPERATURE COEFFICIENT |
|---|---|---|---|---|---|
| Black | 1 | 1 | 1 | | A |
| Brown | 10 | 10 | 10 | 100 | B |
| Red | 100 | 100 | 100 | 200 | C |
| Orange | 1,000 | 1,000 | 1,000 | 300 | D |
| Yellow | 10,000 | | | 400 | E |
| Green | 100,000 | | | 500 | F |
| Blue | 1,000,000 | | | 600 | G |
| Violet | 10,000,000 | | | 700 | |
| Gray | 100,000,000 | | 0.01 | 800 | |
| White | 1,000,000,000 | | 0.1 | 900 | |
| Gold | 0.1 | 0.1 | | 1000 | |
| Silver | 0.01 | 0.01 | | 2000 | |
| No Color | | | | 500 | |

RMA: Radio Manufacturers Association
JAN : Joint Army-Navy

Figure 39. Capacitor Multipliers

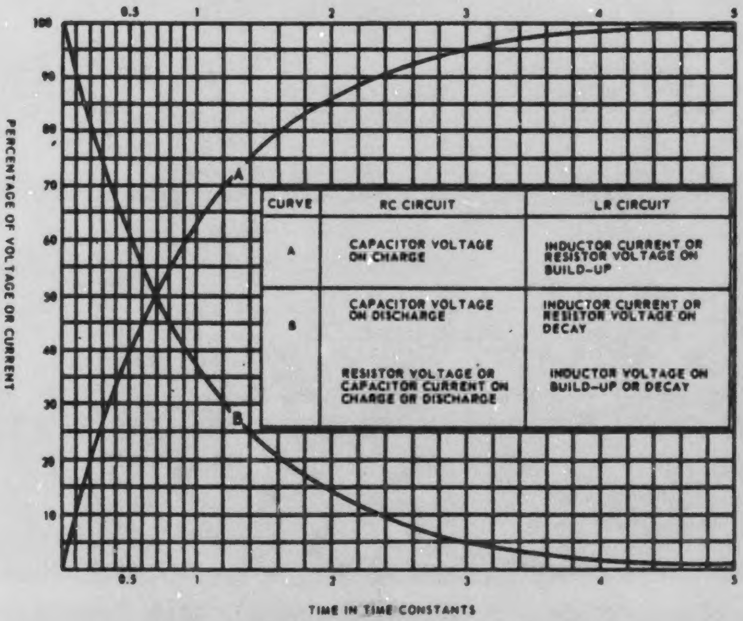


Figure 40. Universal Time Chart

## CONVERSION FACTORS

Radar signal velocity = 186 x $10^3$ statute miles or 162 x $10^3$ nautical miles per second
One statute mile = 5280 ft.
One nautical mile = 6080.2 ft = 1853.184 meters
One radar mile = 12.6 microseconds (signal out + back)
One radar mile = one nautical mile
One inch = 2.54 cm.
One foot = 30.48 cm.
One meter = 39.37 inches
One radian = $\frac{180}{\pi}$ degrees = 57.3°

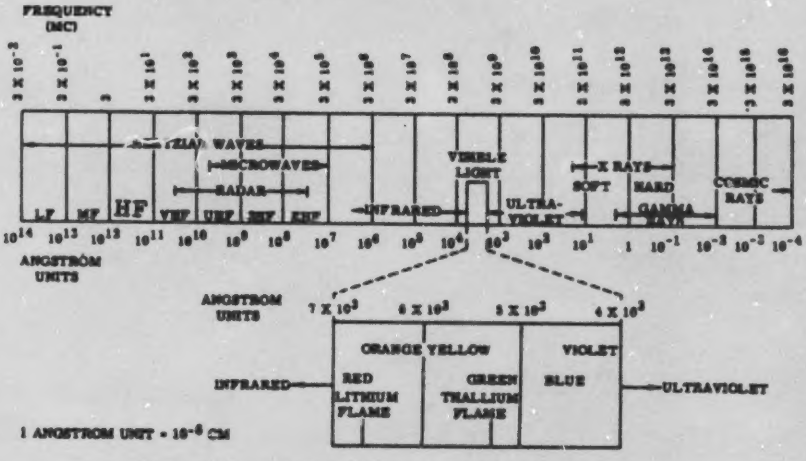


Figure 41. Electromagnetic Wave Spectrum

| Frequency | 3 kc | 30 kc | 300 kc | 3 mc | 30 mc | 300 mc | 3 kmc | 30 kmc 300 kmc |
|---|---|---|---|---|---|---|---|---|
| Designation | VLF | LF | MF | HF | VHF | UHF | SHF<br>← Microwaves → | EHF |
| Bands | | | | | | P<br>L | S<br>X<br>K | |
| Maximum Range (Miles) | World-wide | 2000 | 5000 | 12,000 | Line of sight (sporadic long ranges) | Line of sight | Line of sight | Line of sight |
| Propagation | D-layer reflection | D-layer reflection | E-layer reflection | F-layer reflection | Sporadic ionosphere reflection | Sporadic atmospheric reflection | Sporadic ducting & some atmospheric absorption | Great atmospheric absorption |
| External Interference Sources | Man made & natural | Man made & natural | Man made & natural | Man made & natural | Man made | None | None | None |
| Transmission Lines | Open wire | Open wire | Open wire | Open wire | Open wire & coaxial | Coaxial open wire, & waveguide | Waveguide | Waveguide |
| Applications | Communications, experimental | Communications, navigation | Communications, navigation | Communications, navigation, control, medical | Communications, navigation, television, control, relay, radar, industrial, medical | Communications, navigation, television, control, relay, radar, medical | Communications, navigation, control, relay, radar, industrial, nuclear resonance | Atomic clocks, nuclear, resonance, radar, control, experimental |

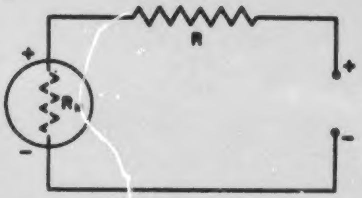
Figure 42. Characteristics of Radio Waves

## D-C METER FORMULAS

**VOLTAGE MULTIPLIERS.**

1. Formula for voltage multipliers.

1.



$$R = \frac{E_{fs}}{I_{fs}} - R_m$$

where R = multiplier resistance in ohms,

$E_{fs}$ = full scale reading required in volts,

$I_{fs}$ = full scale current of meter in amperes,

$R_m$ = meter resistance in ohms.

**MEASURING RESISTANCE.**

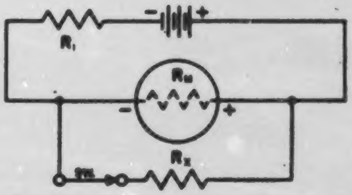
2. Formula for measuring resistance.

a. With milliammeter and battery.[1]

b. With milliammeter, battery, and known resistor.

c. With voltmeter and battery.

2a.



$R_x = R_m \left(\frac{I_2}{I_1 - I_2}\right)$ where $R_x$ = unknown resistance in ohms,

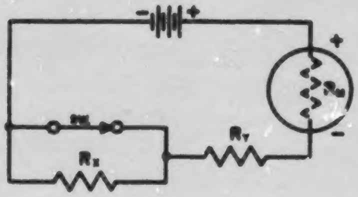
$R_m$ = meter resistance in ohms, or effective meter resistance if a shunted range is used,

$I_1$ = current reading with switch open,

$I_2$ = current reading with switch closed,

$R_1$ = current limiting resistor of sufficient value to keep meter reading on scale when switch is open.

2b.



$$R_x = (R_y + R_m)\left(\frac{I_1 - I_2}{I_2}\right)$$

where $R_x$ = unknown resistance in ohms,

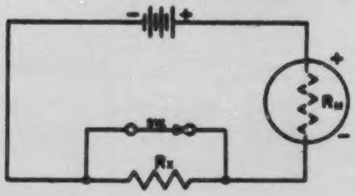
$R_y$ = known resistance in ohms,

$R_m$ = meter resistance in ohms,

$I_1$ = current reading with switch closed,

$I_2$ = current reading with switch open.

2c.



$$R_x = R_m \left(\frac{E_1 - 1}{E_2}\right)$$

where $R_x$ = unknown resistance in ohms,

$R_m$ = meter resistance in ohms, including multiplier resistance if a multiplied range is used,

$E_1$ = voltmeter reading with switch closed,

$E_2$ = voltmeter reading with switch open.

Figure 43. D-C Meter Formulas

| GAGE (AWG) OR (B & S) | DIAMETER INCHES | | | AREA | WEIGHT | LENGTH | RESISTANCE AT 68° F | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min | Nom | Max | Circular Mils | Pounds per M' | Feet per Lb | Ohms per M' | Feet per Ohm | Ohms per Lb |
| 0000 | .4554 | .4600 | .4646 | 211600. | 640.5 | 1.561 | .04901 | 20400. | .00007652 |
| 000 | .4055 | .4096 | .4137 | 167800. | 507.9 | 1.968 | .06180 | 16180. | .0001217 |
| 00 | .3612 | .3648 | .3684 | 133100. | 402.8 | 2.482 | .07793 | 12830. | .0001935 |
| 0 | .3217 | .3249 | .3281 | 105500. | 319.5 | 3.130 | .09827 | 10180. | .0003076 |
| 1 | .2864 | .2893 | .2922 | 83690. | 253.3 | 3.947 | .1239 | 8070. | .0004891 |
| 2 | .2550 | .2576 | .2602 | 66370. | 200.9 | 4.977 | .1563 | 6400. | .0007778 |
| 3 | .2271 | .2294 | .2317 | 52640. | 159.3 | 6.276 | .1970 | 5075. | .001237 |
| 4 | .2023 | .2043 | .2063 | 41740. | 126.4 | 7.914 | .2485 | 4025. | .001966 |
| 5 | .1801 | .1819 | .1837 | 33100. | 100.2 | 9.980 | .3133 | 3192. | .003127 |
| 6 | .1604 | .1620 | .1636 | 26250. | 79.46 | 12.58 | .3951 | 2531. | .004972 |
| 7 | .1429 | .1443 | .1457 | 20820. | 63.02 | 15.87 | .4982 | 2007. | .007905 |
| 8 | .1272 | .1285 | .1298 | 16510. | 49.98 | 20.01 | .6282 | 1592. | .01257 |
| 9 | .1133 | .1144 | .1155 | 13090. | 39.63 | 25.23 | .7921 | 1262. | .01999 |
| 10 | .1009 | .1019 | .1029 | 10380. | 31.43 | 31.82 | .9989 | 1001. | .03178 |
| 11 | .08983 | .09074 | .09165 | 8234. | 24.92 | 40.12 | 1.260 | 794. | .05053 |
| 12 | .08000 | .08081 | .08162 | 6530. | 19.77 | 50.59 | 1.588 | 629.6 | .08035 |
| 13 | .07124 | .07196 | .07268 | 5178. | 15.68 | 63.80 | 2.003 | 499.3 | .1278 |
| 14 | .06344 | .06408 | .06472 | 4107. | 12.43 | 80.44 | 2.525 | 396.0 | .2032 |
| 15 | .05650 | .05707 | .05764 | 3257. | 9.858 | 101.4 | 3.184 | 314.0 | .3230 |
| 16 | .05031 | .05082 | .05133 | 2583. | 7.818 | 127.9 | 4.016 | 249.0 | .5136 |
| 17 | .04481 | .04526 | .04571 | 2048. | 6.200 | 161.3 | 5.064 | 197.5 | .8167 |
| 18 | .03990 | .04030 | .04070 | 1624. | 4.917 | 203.4 | 6.385 | 156.6 | 1.299 |
| 19 | .03553 | .03589 | .03625 | 1288. | 3.899 | 256.5 | 8.051 | 124.2 | 2.065 |
| 20 | .03164 | .03196 | .03228 | 1022. | 3.092 | 323.4 | 10.15 | 98.5 | 3.283 |
| 21 | .02818 | .02846 | .02874 | 810.1 | 2.452 | 407.8 | 12.80 | 78.11 | 5.221 |
| 22 | .02510 | .02535 | .02560 | 642.4 | 1.945 | 514.2 | 16.14 | 61.95 | 8.301 |
| 23 | .02234 | .02257 | .02280 | 509.5 | 1.542 | 648.4 | 20.36 | 49.13 | 13.20 |
| 24 | .01990 | .02010 | .02030 | 404.0 | 1.223 | 817.7 | 25.67 | 38.96 | 20.99 |
| 25 | .01770 | .01790 | .01810 | 320.4 | .9699 | 1031. | 32.37 | 30.90 | 33.37 |
| 26 | .01578 | .01594 | .01610 | 254.1 | .7692 | 1300. | 40.81 | 24.50 | 53.06 |
| 27 | .01406 | .01420 | .01434 | 201.5 | .6100 | 1639. | 51.47 | 19.43 | 84.37 |
| 28 | .01251 | .01264 | .01277 | 159.8 | .4837 | 2067. | 64.90 | 15.41 | 134.2 |
| 29 | .01115 | .01126 | .01137 | 126.7 | .3836 | 2607. | 81.83 | 12.22 | 213.3 |
| 30 | .00993 | .01003 | .01013 | 100.5 | .3042 | 3287. | 103.2 | 9.691 | 339.2 |
| 31 | .008828 | .008928 | .009028 | 79.7 | .2413 | 4145. | 130.1 | 7.685 | 539.3 |
| 32 | .007850 | .007950 | .008050 | 63.21 | .1913 | 5227. | 164.1 | 6.095 | 857.6 |
| 33 | .006980 | .007080 | .007180 | 50.13 | .1517 | 6591. | 206.9 | 4.833 | 1364. |
| 34 | .006205 | .006305 | .006405 | 39.75 | .1203 | 8310. | 260.9 | 3.833 | 2168. |
| 35 | .005515 | .005615 | .005715 | 31.52 | .09542 | 10480. | 329.0 | 3.040 | 3448. |
| 36 | .004900 | .005000 | .005100 | 25.00 | .07568 | 13210. | 414.8 | 2.411 | 5482. |
| 37 | .004353 | .004453 | .004553 | 19.83 | .06001 | 16660. | 523.1 | 1.912 | 8717. |
| 38 | .003865 | .003965 | .004065 | 15.72 | .04759 | 21010. | 659.6 | 1.516 | 13860. |
| 39 | .003431 | .003531 | .003631 | 12.47 | .03774 | 26500. | 831.8 | 1.202 | 22040. |
| 40 | .003045 | .003145 | .003245 | 9.888 | .02993 | 33410. | 1049. | 0.9534 | 35040. |
| 41 | .00270 | .00280 | .00290 | 7.8400 | .02373 | 42140. | 1323. | .7559 | 55750. |
| 42 | .00239 | .00249 | .00259 | 6.2001 | .01877 | 53270. | 1673. | .5977 | 89120. |
| 43 | .00212 | .00222 | .00232 | 4.9284 | .01492 | 67020. | 2104. | .4753 | 141000. |
| 44 | .00187 | .00197 | .00207 | 3.8809 | .01175 | 85100. | 2672. | .3743 | 227380. |
| 45 | .00166 | .00176 | .00186 | 3.0976 | .00938 | 106600. | 3348. | .2987 | 356890. |
| 46 | .00147 | .00157 | .00167 | 2.4649 | .00746 | 134040. | 4207. | .2377 | 563900. |

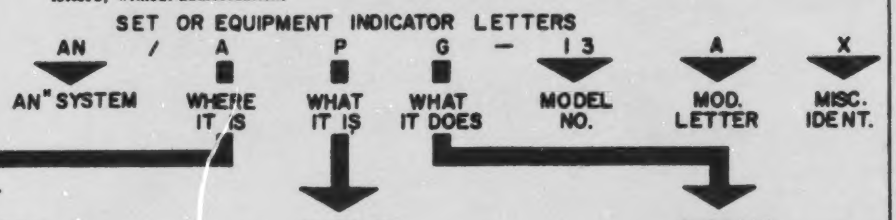
Figure 44. AWG Copper Wire Table

## NOMENCLATURE POLICY

(See JANAP 196 for Statement of Policies)

1. AN Nomenclature will be assigned to:
   - A. Complete sets of equipment and major components of military design.
   - B. Groups of articles of either commercial or military design which are grouped for military purpose.
   - C. Major articles of military design which are not part of or used with a set.
   - D. Commercial articles when nomenclature will facilitate military identification and/or procedures.
2. AN Nomenclature will not be assigned to:
   - A. Articles cataloged commercially except in accordance with paragraph 1.D.
   - B. Minor components of military design for which other adequate means of identification are available.
   - C. Small piece parts such as capacitors and resistors.
   - D. Articles having other adequate identification in joint military specifications.
3. Nomenclature assignments will remain unchanged regardless of later changes in installation and/or application.

IMPORTANT. — All personnel are cautioned against originating or changing any part of any nomenclature assignment, including modification letters, without authorization.



### INSTALLATION

- A--Airborne (installed and operated in aircraft).
- B--Underwater mobile, submarine.
- C--Air transportable (inactivated, do not use).
- D--Pilotless carrier.
- F--Fixed.
- G--Ground, general ground use (include two or more ground-type installations).
- K--Amphibious.
- M--Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment).
- P--Pack or portable (animal or man).
- S--Water surface craft.
- T--Ground, transportable.
- U--General utility (includes two or more general installation classes, airborne, shipboard, and ground).
- V--Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, etc., such as tanks).
- W--Water surface and underwater.

### TYPE OF EQUIPMENT

- A--Invisible light, heat radiation.
- B--Pigeon.
- C--Carrier.
- D--Radiac.
- E--Nupac.
- F--Photographic.[1]
- G--Telegraph or teletype.
- I --Interphone and public address.
- J--Electromechanical or inertial wire covered.
- K--Telemetering.
- L--Countermeasures.
- M--Meteorological.
- N--Sound in air.
- P--Radar.
- Q--Sonar and underwater sound.
- R--Radio.
- S--Special types, magnetic, etc., or combinations of types.
- T--Telephone (wire).
- V--Visual and visible light.
- W--Armament (peculiar to armament, not otherwise covered).
- X--Facsimile or television.
- Y--Data processing.

### PURPOSE

- A--Auxiliary assemblies (not complete operating sets used with or part of two or more sets or sets series).
- B--Bombing.
- C--Communications (receiving and transmitting).
- D--Direction finder, reconnaissance, and/or surveillance.
- E--Ejection and/or release.
- G--Fire-control or searchlight directing.
- H--Recording and/or reproducing (graphic meteorological and sound).
- K--Computing.
- L--Searchlight control (inactivated, use G).
- M--Maintenance and test assemblies (including tools).
- N--Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach, and landing).
- P--Reproducing (inactivated, do not use).
- Q--Special, or combination of purposes.
- R--Receiving, passive detecting.
- S--Detecting and/or range and bearing, search.
- T--Transmitting.
- W--Automatic flight or remote control.
- X--Identification and recognition.

---

[1] Not for US use except for assigning suffix letters to previously nomenclatured items.

Figure 45. Nomenclature System

Figure 45. Nomenclature System (Contd)

| COMPONENT INDICATORS | FAMILY NAME | EXAMPLES OF USE (not to be construed as limiting the application of the component indicator). |
|---|---|---|
| AB | Supports, antenna | Antenna mounts, mast bases, mast sections, towers, etc. |
| AM | Amplifiers | Power, audio, interphone, radio frequency, video, electronic control, etc. |
| AS | Antennae, complex | Arrays, parabolic type, masthead, etc. |
| AT | Antennae, simple | Whip or telescopic loop, dipole, reflector, etc. |
| BA | Battery, primary type | B batteries, battery packs, etc. |
| BB | Battery, secondary type | Storage batteries, battery packs, etc. |
| BZ | Signal devices, audible | Buzzers, gongs, horns, etc. |
| C | Controls | Control box, remote tuning control etc. |
| CA | Commutator assemblies, sonar | Peculiar to sonar equipment. |
| CB | Capacitor bank | Used as a power supply. |
| CG | Cable Assemblies, RF | RF cables, waveguides, transmission lines, etc., with terminals. |
| CK | Crystal kits | A kit of crystals with holders. |
| CM | Comparators | Compares two or more input signals. |
| CN | Compensators | Electrical and/or mechanical compensating regulating or attenuating apparatus. |
| CP | Computers | A mechanical and/or electronic mathematical calculating device. |
| CR | Crystals | Crystal in crystal holder. |
| CU | Couplers | Impedance coupling devices, directional couplers, etc. |
| CV | Converters (electronic) | Electronic apparatus for changing the phase, frequency, or from "one" medium to "another." |
| CW | Covers | Cover, bag, roll, cap, radome, nacelle, etc. |
| CX | Cable assemblies, nonRF | NonRF cables with terminals, test leads, also composite cables of RF and nonRF conductors. |
| CY | Cases and cabinets | Rigid and semirigid structure for enclosing or carrying equipment. |
| D | Dispensers | Chaff dispensers. |
| DA | Load, dummy | RF and nonRF test loads. |
| DT | Detecting heads | Magnetic pickup device, search coil, hydrophone, etc. (see RF). |
| DY | Dynamotors | Dynamotor power supply. |
| E | Hoists | Sonar hoist assembly, etc. |
| F | Filters | Band-pass, noise, telephone, wave traps, etc. |
| FN | Furniture | Chairs, desks, tables, etc. |
| FR | Frequency measuring devices | Frequency meters, tuned cavity, etc. |
| G | Generators, power | Electrical power generators without prime movers (see PU & PD). |
| GO | Goniometers | Goniometers of all types. |
| GP | Ground rods | Ground rods, stakes, etc. |
| H | Head, hand, and chest sets | Includes earphone. |
| HC | Crystal holder | Crystal holder less crystal. |
| HD | Air-conditioning apparatus | Heating, cooling, dehumidifying, pressure, vacuum devices, etc. |
| ID | Indicators, noncathode-ray tube | Calibrated dials and meters, indicating lights, etc. (see IP). |
| IL | Insulators | Strain, standoff, feed-through, etc. |
| IM | Intensity measuring devices | Includes SWR gear, field intensity and noise meters, slotted lines, etc. |
| IP | Indicators, cathode-ray tube | Azimuth, elevation, panoramic, etc. |
| J | Junction devices | Junction, jack and terminal boxes, etc. |
| KY | Keying devices | Mechanical, electrical and electronic keyers, coders, interrupters, etc. |
| LC | Tools, line construction | Includes special apparatus such as cable plows, etc. |
| LS | Loudspeakers | Separately housed loudspeakers, intercommunication station. |
| M | Microphones | Radio, telephone, throat, hand, etc. |
| MA | Magazines | Magnetic tape or wire, etc. |
| MD | Modulators | Device for varying amplitude, frequency or phase. |
| ME | Meters | Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc. |
| MF | Magnets or magnetic field generators | Magnetic tape or wire eraser, electromagnet, permanent magnet, etc. |
| MK | Miscellaneous kits | Maintenance, modification, etc., except tool and crystal (see CK, TK). |
| ML | Meteorological devices | Barometer, hygrometer, thermometer, scales, etc. |
| MT | Mountings | Mountings, racks, frames, stands, etc. |
| MX | Miscellaneous | Equipment not otherwise classified, includes subassemblies. Do not use if better indicator is available. |

Figure 45. Nomenclature System (Contd)

| COMPONENT INDICATORS | FAMILY NAME | EXAMPLES OF USE (not to be construed as limiting the application of the component indicator). |
|---|---|---|
| MU | Memory units | Memory units. |
| O | Oscillators | Master frequency, blocking, multivibrators, etc. (for test oscillators, see SG). |
| OA | Operating assemblies | Assembly of operating units not otherwise covered, used with or part of one set or set series. |
| OC | Oceanographic devices | Bathythermographs, etc. |
| OS | Oscilloscope, test | Test oscilloscopes for general test purposes. |
| PD | Prime drivers | Gasoline engines, electric motors, Diesel motors, etc. |
| PF | Fittings, pole | Cable hanger, clamp, protectors, etc. |
| PG | Pigeon articles | Container, loft, vest, etc. |
| PH | Photographic articles | Camera, projector, sensitometer, etc. |
| PP | Power supplies | Nonrotating machine type such as vibrator pack, rectifier, thermoelectric, etc. |
| PT | Plotting equipments | Except meteorological. Boards, maps, plotting table, etc. |
| PU | Power equipments | Rotating power equipment except dynamotors, motor-generator, etc. |
| R | Receivers | Receivers, all types except telephone. |
| RC | Reels | Reel cable (see RI). |
| RD | Recorder-reproducers | Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc. |
| RE | Relay assemblies | Electrical, electronic, etc. |
| RF | Radio frequency component | Composite component of RF circuits. Do not use if better indicator is available. |
| RG | Cables, RF, Bulk | RF cable, waveguides, transmission lines, etc., without terminals. |
| RL | Reeling machines | Mechanisms for dispensing and rewinding antenna or field wire, recording wire or tape, etc. |
| RO | Recorders | Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc. |
| RP | Reproducers | Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc. |
| RR | Reflectors | Target, confusion, etc. Except antenna reflectors (see AT). |
| RT | Receiver and transmitter | Radio and radar transceivers, composite transmitter and receiver, etc. |
| S | Shelters | House, tent, protective shelter, etc. |
| SA | Switching devices | Manual, impact, motor driven, pressure operated, etc. |
| SB | Switchboards | Telephone, fire control, power, panel, etc. |
| SG | Generators, signal | Test oscillators, noise generators, etc. (see O). |
| SM | Simulators | Flight, aircraft, target, signal, etc. |
| SN | Synchronizers | Equipment to coordinate two or more functions. |
| ST | Straps | Harness, straps, etc. |
| SU | Optical device | Telescopes, periscopes, projectors, and boresighting scopes. |
| T | Transmitters | Transmitters, all types, except telephone. |
| TA | Telephone apparatus | Miscellaneous telephone equipment. |
| TB | Towed body | Towed underwater body or fish, paravance, etc. |
| TC | Towed cable | Articulated towing strut, faired cable, etc. |
| TD | Timing devices | Mechanical and electronic timing devices, range device, multiplexers, electronic gates, etc. |
| TF | Transformers | Transformers when used as separate items. |
| TG | Positioning devices | Tilt and/or train assemblies. |
| TH | Telegraph apparatus | Miscellaneous telegraph apparatus. |
| TK | Tool kits | Miscellaneous tool assemblies. |
| TL | Tools | All types except line construction (see LC). |
| TN | Tuning units | Receiver, transmitter, antenna, tuning units, etc. |
| TR | Transducers | Magnetic heads, phonopickups, sonar transducers, vibration pickups, etc. (see H, LS, and M). |
| TS | Test items | Test and measuring equipment not otherwise included; boresighting and alignment equipment. |
| TT | Teletypewriter and facsimile apparatus | Miscellaneous tape, teletype, facsimile equipment, etc. |
| TV | Tester, tube | Electronic tube tester. |
| TW | Tapes and recording wires | Recording tape and wire, splicing, electrical insulating tape, etc. |

Figure 45. Nomenclature System (Contd)

| COMPONENT INDICATORS | FAMILY NAME | EXAMPLES OF USE (not to be construed as limiting the application of the component indicator). |
|---|---|---|
| U | Connectors, audio and power | Unions, plugs, sockets, adapters, etc. |
| UG | Connectors, RF | Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc. |
| V | Vehicles | Carts, dollies, trucks, trailers, etc. |
| VS | Signaling equipment, visual | Flag sets, aerial panels, signal lamp equipment, etc. |
| WD | Cables, two conductor | NonRF wire, cable and cordage in bulk (see RG). |
| WF | Cables, four conductor | NonRF wire, cable and cordage in bulk (see RG). |
| WM | Cables, multiple conductor | NonRF wire, cable and cordage in bulk (see RG). |
| WS | Cables, single conductor | NonRF wire, cable and cordage in bulk (see RG). |
| WT | Cables, three conductor | NonRF wire, cable and cordage in bulk (see RG). |
| ZM | Impedance measuring devices | Used for measuring Q, C, L, R, or PF, etc. |

| NAME | CAPITAL | SMALL | COMMONLY USED TO DESIGNATE[1] |
|---|---|---|---|
| alpha | Α | α | Angles, coefficients, attenuation constant, absorption factor area. |
| beta | Β | β | Angles, coefficients, phase constant. |
| gamma | Γ | γ | Complex propagation constant (capital), specific gravity, angles, electric conductivity, propagation constant. |
| delta | Δ | δ | Increment or decrement (capital or small), determinant (capital), permittivity (capital), density, angles. |
| epsilon | Ε | ε | Dielectric constant, permittivity, base of natural logarithms, electric intensity. |
| zeta | Ζ | ζ | Coordinates, coefficients. |
| eta | Η | η | Intrinsic impedance, efficiency, surface-charge density, hysteresis, coordinates. |
| theta | Θ | θ | Angular phase displacement, time constant, reluctance, angles. |
| iota | Ι | ι | Unit vector. |
| kappa | Κ | κ | Susceptibility, coupling coefficient. |
| lambda | Λ | λ | Permeance (capital) wavelength attenuation constant. |
| mu | Μ | μ | Permeability, amplification factor, prefix micro. |
| nu | Ν | ν | Reluctivity, frequency. |
| xi | Ξ | ξ | Coordinates. |
| omicron | Ο | ο | |
| pi | Π | π | 3.1416 |
| rho | Ρ | ρ | Resistivity, volume charge density, coordinates. |
| sigma | Σ | σ | Summation (capital), surface-charge density, complex propagation constant, electrical conductivity, leakage coefficient. |
| tau | Τ | τ | Time constant volume resistivity, time-phase displacement transmission-factor density. |
| upsilon | Υ | υ | |
| phi | Φ | φ | Scalar potential (capital), magnetic flux, angles. |
| chi | Χ | χ | Electric susceptibility, angles. |
| psi | Ψ | ψ | Dielectric flux, phase difference, coordinates, angles. |
| omega | Ω | ω | Resistance in ohms (capital), solid angle (capital), angular velocity. |

[1] Small letter is used except where capital is indicated.

Figure 46. Greek Alphabet

| ICAO PHONETIC | | PRONUNCIATION |
|---|---|---|
| A | Alfa | Al-fah |
| B | Bravo | Brah-voh |
| C | Charlie | Char-lee (or Shar-lee) |
| D | Delta | Dell-tah |
| E | Echo | Eck-oh |
| F | Foxtrot | Foks-trot |
| G | Golf | Golf |
| H | Hotel | Hoh-tell |
| I | India | In-dee-ah |
| J | Juliett | Jew-lee-ett |
| K | Kilo | Key-loh |
| L | Lima | Lee-mah |
| M | Mike | Mike |
| N | November | No-vem-ber |
| O | Oscar | Oss-cah |
| P | Papa | Pah-pah |
| Q | Quebec | Keh-beck |
| R | Romeo | Row-me-oh |
| S | Sierra | See-air-rah |
| T | Tango | Tang-go |
| U | Uniform | You-nee-form (or oo-nee-form) |
| V | Victor | Vik-tah |
| W | Whiskey | Wiss-key |
| X | X-ray | Ecks-ray |
| Y | Yankee | Yang-key |
| Z | Zulu | Zoo-loo |

Figure 47. Phonetic Alphabet

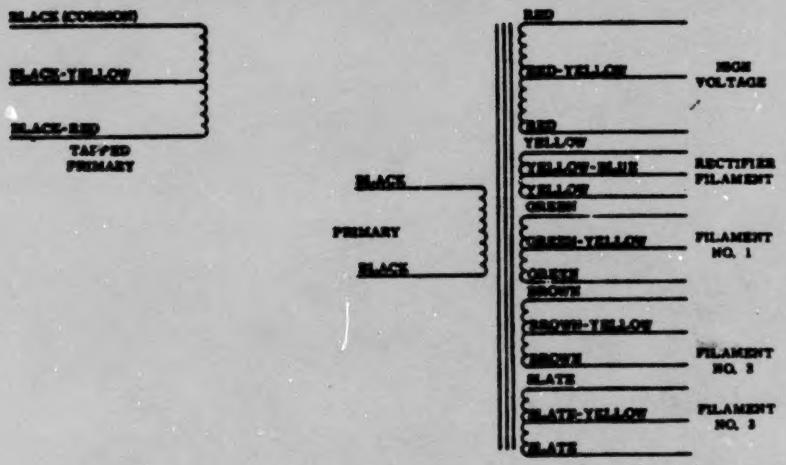


Figure 48. Power Transformer Color Code

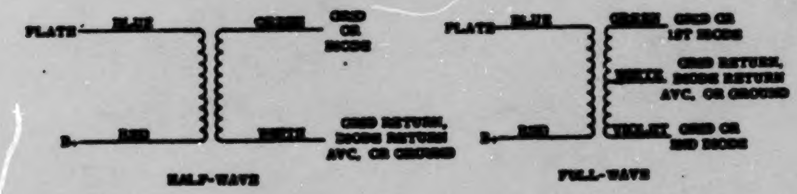


Figure 49. Intermediate-Frequency Transformer Color Code

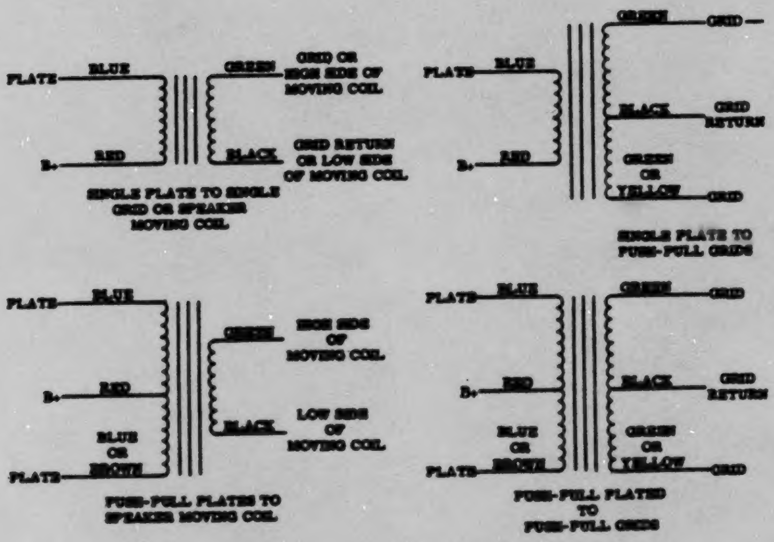


Figure 50. Audio-Frequency Transformer Color Code

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# BASIC LAWS AND COMMON IDENTITIES OF BOOLEAN ALGEBRA

**Identity:** $A = A$; $\bar{A} = \bar{A}$

**Commutative:** $AB = BA$; $A + B = B + A$

**Associative:** $A(BC) = ABC$; $A + (B+C) = A + B + C$

**Idempotent:** $AA = A$; $A + A = A$

**Double Negative:** $\bar{\bar{A}} = A$

**Complementary:** $A\bar{A} = 0$; $A + \bar{A} = 1$

**Intersection:** $A \cdot 1 = A$; $A \cdot 0 = 0$

**Union:** $A + 1 = 1$; $A + 0 = A$

**De Morgan:** $\overline{AB} = \bar{A} + \bar{B}$; $\overline{A + B} = \overline{AB}$

**Distributive:** $A(B+C) = AB + AC$; $A + BC = (A+B)(A+C)$

**Absorption:** $A(A+B) = A + AB = A$

**Common Identities:** $A(\bar{A}+B) = AB$; $A + \bar{A}B = A + B$

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KEP-ST-1

Technical Training

# Electronic Principles (Modular Self-Paced)

## Volume 1

## DC PRINCIPLES

1 September 1975

AIR TRAINING COMMAND

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Radar Principles Branch
Keesler Air Force Base, Mississippi

Student Text KEP-ST-I
3AQR3X020-X
1 September 1975

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## VOLUME I

## DC PRINCIPLES

This student text is the prime source of information for achieving the objectives of this block of instruction. This publication is designed for training purposes only and should not be used as a basis for job performance in the field.

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Supersedes KEP-ST-I, 1 May 1974

# Chapter 1

## SAFETY AND FIRST AID

1-1. First and foremost in the study of electronics is an area which concerns everyone; safety and first aid. Personnel working around and with electrical and electronic equipment must be constantly aware of safety and first aid procedures. Future electronic technicians should be familiar with major causes of accidents, hazards, and precautions related to electronic circuits, first aid for electrical shock victims, and identification and control of various types of fires.

### 1-2. Accident Causes

1-3. Two areas of serious concern involving an accident are CAUSE and EFFECT. Effect is the reason the Air Force is concerned. Accidents result in the loss, damage, or destruction of property, as well as injury and death to personnel. Due to the costly factors which accompany accidents, the Air Force is constantly searching for methods to improve safety procedures.

1-4. Causes of accidents also give the Air Force concern. Fortunately, there are many statistics which show that 98% of all accidents are avoidable. Amazing, but true! With such a wide area in which improvement can be made, it is reasonable that everyone can contribute something toward reducing accidents. Major causes are unsafe acts due to human error and material failure.

1-5. The unsafe acts of individuals cause 88% of all accidents. Material failure accounts for 10%. Although unsafe acts of personnel are of great concern, the Air Force must concentrate on ALL accident causes.

1-6. Human error may take the form of inattentiveness, excitability, impatience, carelessness, and even ignorance. Watch anyone who seems to be "accident prone." One or more of these undesirable characteristics will be present in his everyday behavior. Such individuals are a hazard to the personnel with whom they work and associate.

1-7. Accidents caused by material failure are usually difficult to anticipate. These accidents are caused primarily by equipment that has flaws, undetected during inspections. Included are screwdrivers with broken or cracked handles, meters with internal shorts, rubber gloves with small holes, stepladders with cracked rungs, and all other tools that are not in servicable condition. Careful inspections, conducted frequently, will reduce the number of accidents caused by faulty equipment.

### 1-8. Electrical Hazards

1-9. The dangers of electricity can be avoided by the use of common sense, safety precautions, and knowledge. High voltages cause electrical shock and high currents cause burning. Voltage and current are inseparable in electrical hazards.

1-10. High voltages are present in most electronic equipment. It is imperative that all personnel know and understand the safety procedures established for each type of equipment. Most high voltage equipment is turned off when maintenance is being performed. Turning on the equipment during such maintenance could be disastrous. All types of Air Force equipment have built-in safety devices, but they are not a guarantee against careless or thoughtless individuals.

1-11. All electronic equipments have fuses, either within the device itself or in the wiring leading to the device. A fuse is a current-sensitive element which opens (and stops current) whenever excessive current is drawn. The size and type of fuse is based on the amount of current (in amperes) that the circuit can safely handle. A blown fuse is not a fault. The trouble that caused it to blow must be located and corrected. Never replace a blown fuse with anything but a fuse of the correct voltage and current rating.

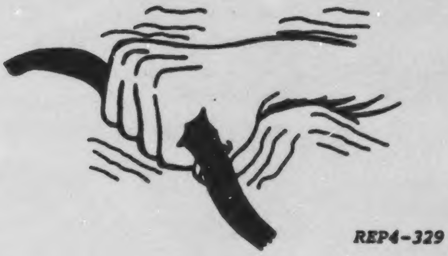


Figure 1-1

1-12. Unfortunately, the fuse that will protect the equipment will not necessarily protect those who are operating the equipment. For example, the size of the house fuse is determined by the size of the wires leading to the wall socket, and NOT by what is to be plugged into the wall socket. A very small amount of current passing through the chest can cause death, yet this same amount of current would NOT blow the fuse. The point is, a fuse will not protect human life.

1-13. What is the smallest amount of electrical current required to electrocute a person? No medical authority will state a definite amount because of the many factors involved. The lethal amount depends upon the PERSON INVOLVED AND HIS STATE OF HEALTH, AREA OF THE BODY INVOLVED, LENGTH OF TIME THE SHOCK IS RECEIVED, and TYPE OF ELECTRICAL CURRENT.

1-14. Physically severe electrical shock will have two main types of effects: burning and paralysis. Either can range from minor, temporary damage to fatal injury.

1-15. Even people in excellent health may be severely affected by minor electrical shock. Some people respond by going into psychological shock. This is the same thing suffered after a narrow escape from a traffic accident or a severe fright.

1-16. The next three important factors are interrelated and must be considered together: What part of the body is involved, the amount of electrical current, and how long the shock is received.

1-17. Suppose, for example, a shock is received from the little finger to the elbow. The electrical current will pass through the forearm. When the current is low, an unpleasant tingle is felt. At a higher current, burns will be received on the finger and the elbow where the current enters and leaves. Also, internal burns within the arm will cause tissue and nerve damage that may be permanent. The higher the current, the more the damage! A shock of this type does not usually last too long because the muscles in the arm will contract and break the current path. This muscular contraction can be helpful or it can cause more harm. Contraction of the fingers can lock the hand to a wire instead of pulling it away. See figure 1-1.

1-18. Contraction of the arm muscles can cause injury with tools held in the hand. Any tool can become a deadly weapon as a result of an otherwise minor shock. Keep hands free of extra tools when checking equipment. Contraction of leg or other body muscles may cause an accidental fall.

1-19. Injury received from an electrical shock could range from minor to fatal, depending on the part of the body involved, even though the amount of current is the same.

1-20. The most severe shocks are those that involve the brain or vital organs in the chest and abdominal areas. The brain is shielded to some extent by the skull but the chest and abdominal areas are relatively unprotected. To limit the body area involved, be a one-armed technician. Do not use both hands unless absolutely necessary. A man using both hands provides a path for electrical current through the vital chest area.

1-21. Fatal shocks usually involve paralysis. The brain's messages can be disrupted so that breathing or heart action becomes disorganized or stopped. Sometimes the heart is still operating but instead of a steady, rhythmic beat, the heart flutters with a series of uncoordinated, rapid, weak pulsations. This is called "ventricular fibrillation" and is fatal if it continues for any appreciable length of time.

1-22. The key points are as follows:

CURRENT - Electrical current can kill. The more the current, the more the injury and the greater chance of death.

AREA - The more of the body involved, the greater the injury. If the area involved contains vital organs, the chance of death is much greater.

TIME - The longer the shock is received, the greater the injury and the higher the chance of death.

TURN THE POWER OFF - Never work on a "hot" circuit unless absolutely necessary.

DON'T EXPERIMENT - Don't touch a wire with the fingers to see what will happen. Remember, electricity is invisible. A bare wire may be a high voltage wire. To find out, check with a meter and not the fingers.

DO NOT WEAR METALLIC JEWELRY, WATCHES, RINGS, ID BRACELETS, etc., while working on equipment.

1-23. No qualified technician will come in out of the rain and start working on electrical equipment, but people will do essentially the same thing while they are hot and perspiring. Perspiration is a good conductor of electricity and spreads the shock over the entire body surface. Keep the body as dry as possible, and never stand in water or on a damp surface when working with electrical equipment.

1-24. Remember these important points. When working on equipment, TURN OFF THE POWER. Know the equipment. Keep the body of metal tools from coming into contact with electrical current sources. Make certain that all equipment is properly wired and grounded.

1-25. First Aid for Electrical Shock Victims

1-26. When a person comes in contact with a wire carrying electricity, many things can happen and these depend primarily on the amount of electricity involved. Sometimes victims are "frozen" to the wires, or they may be knocked off their feet. If the electrical current is high and the victim is in a position to provide a good path for the current, the results are usually disasterous. The victim may be burned over large parts of his body. Such victims must receive artificial respiration immediately if they are to be saved.

1-27. The electricity in normal tabletop radios can be deadly under certain circumstances. People are killed by radios while they are taking a bath. The metal tub and water pipes provide a good electrical-current path that can make household electricity deadly.

1-28. When someone does come in contact with a "hot" wire, TURN OFF THE POWER as quickly as possible. If the switch is not handy, DON'T WASTE TIME! Remove the victim from the electrical source by using a dry wooden pole, dry clothing, a rope, a belt, or any other material that will not carry electricity. If clothing, rope, or a cord is used, make it into a loop and put it over a foot, leg, or arm to drag the victim off the electrical source. Be careful not to touch the victim, or you will also become a victim.

1-29. Severe electrical shock usually causes the victim to stop breathing. Artificial respiration must be started as soon as the victim is free of the electrical source.

1-30. Artificial Respiration

1-31. The success of artificial respiration is often dependent on how soon it is started. DON'T WASTE TIME moving the victim to an ideal location and DON'T WAIT for mechanical equipment.

1-32. There are four methods of artificial respiration:

a. Prone pressure.
b. Back pressure, arm lift.
c. Back pressure, hip lift.
d. Mouth to mouth.

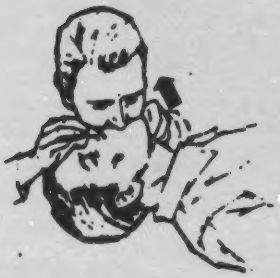


Figure 1-2

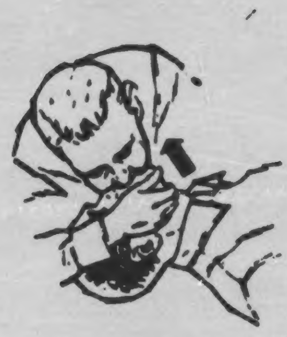


Figure 1-3

1-33. It has been proven that mouth-to-mouth resuscitation is far better than the other three methods. To begin, place the victim on his back and use your fingers to clean his mouth and throat of any foreign matter and make certain he hasn't swallowed his tongue.

1-34. Next, tilt his head backward so that he is in a sword-swallowing position. See figure 1-2. This will insure that his neck is not kinked and that there is a clear passage into his lungs.

1-35. Approach the victim's head preferably from his left side and hold his low jaw up by putting your fingers under his chin and your thumb on his lower teeth. Then pull on his jaw until his lower teeth are further forward than his upper teeth.

1-36. Next, use your right hand to close the victim's nose. Take a deep breath and cover the victim's open mouth with your own, to form an airtight seal (figure 1-3). Blow rapidly until the victim's chest rises. (This should be done forcibly with adults but gently with children.) After his chest rises, remove your mouth from the victim and allow him to exhale by himself.

1-37. This action should be repeated 12 to 20 times a minute. You will find that you are breathing faster than usual in order to get enough air for yourself. Actually humans use only about 25 percent of the oxygen they inhale, so the victim is getting all he needs. Continue rhythmically without interruption until the victim either starts breathing or is pronounced beyond all help by a doctor.

1-38. Bleeding

1-39. Any cut or wound that is severe enough to bleed requires attention. Depending on the severity, the required first aid may range from a band-aid to a tourniquet. Anyone who is bleeding badly is completely dependent on those around him to save his life. In such an event, there are two things which must be done quickly: stop the bleeding and prevent shock. Many people have died of shock from wounds that were not otherwise serious enough to cause death.

1-40. Bleeding wounds can be put into two broad categories: those which involve an artery, and those which do not. If an artery has not been damaged, use a medical dressing or other clean cloth and apply pressure directly on the wound. The pressure will reduce the amount of blood flowing from the wound and will also aid coagulation. If the wound is in an arm or leg, and a broken bone is not involved, raise the limb. This will decrease the flow of blood.

1-41. If an artery has been cut, the blood will gush in spurts with each beat of the victim's heart. This type of wound is naturally much more serious, and prompt attention is required. The flow of blood into the area must be drastically reduced or shut off completely. The best way to do this is to use medical dressings and apply pressure directly to the wound. If the wound is on the limbs and pressure does not reduce or shut off the flow of blood, apply a tourniquet between the wound and the heart. Once applied, a tourniquet should be left in place until removed by a medical officer.

1-42. Some wounds seem to bleed despite anything that is tried. In this case, the person applying the first aid should know how to locate the six pressure points which are on each side of the body. These points are shown in figure 1-4. Pressure that is properly applied at these points will adequately shut off the blood source to the affected part of the body.

1-43. The pressure points in the groin and neck are particularly important. If the wound is too high to apply a tourniquet on the leg, use the pressure point in the groin. Use a neck pressure point only as a last resort, when other methods of stopping the bleeding have failed. Do not apply pressure to both neck points at the same time.

1-44. Shock was previously mentioned in this lesson, and it was stated that precautionary measures against it must be taken quickly after an accident. There are many symptoms which indicate a person is in a state of shock. He will be pale and wet with sweat, have a rapid but weak pulse, and he may be thirsty, gasp for air, and be faint.

1-45. To prevent or treat shock, begin by making the patient as comfortable as you can. Act as calmly as possible, and reassure him that he will be all right. Remove any bulky items he may have been carrying and loosen his belt and clothes. Handle him as gently as possible and don't move him unless it's necessary. Use anything available to keep him warm. If he gets cold, it will increase the degree of shock. If he is unconscious, place him flat on his stomach with his face to one side. This will keep him from choking should he vomit.

1-46. If the wounded man is conscious, give him warm coffee, tea, or cocoa, but no alcohol. If oxygen is available, give it to him as this will help revive him. The most important thing to remember is to TREAT FOR SHOCK EVEN THOUGH THERE ARE NO APPARENT SYMPTOMS.

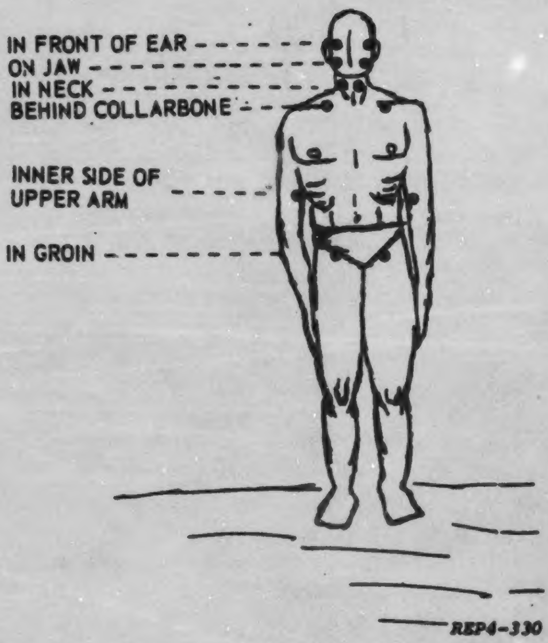


Figure 1-4

1-47. The third important step to follow, when confronted with an accident victim who is bleeding, is to keep the wound as clean as possible. A dressing will protect the wound from germs, dirt, and further injury. Keep your hands off the wound when you put on the dressing, and don't touch the side of the dressing that is put against the wound. Cut or tear clothing away from the area that is injured.

1-48. Treatment of Burns

1-49. First-aid treatment of those persons with severe burns is complicated by the fact that they invariably lapse into a state of shock. In addition, the first-line defense against infection, the skin, is sometimes burned away. Burns are a further cause for frustration because they are always accompanied by extreme pain. It is therefore obvious that three things must be done as quickly as possible for burn victims:

a. Protect them against shock.

b. Protect them against infection.

c. Make them as comfortable as possible.

1-50. Treatment for shock was covered previously, so let's concentrate on protection against infection. Unless morphine is available, there is very little you can do to make him comfortable other than to move him gently into a more comfortable position. The prime thing to remember is to keep the burn from becoming infected by dirt or other foreign substances. The first thing to do is cut or tear the clothing away from the burn, but do not attempt to remove any cloth that may be stuck to the injured area. If sterile gauze or bandage is available, cover the burn area as gently as possible. If there is little danger of dirt or other harmful foreign substances getting into the burn, cover the area with a clean cloth.

1-51. Never put grease, butter, or ointment on a severe burn, as they will have to be painfully removed later by the medics. Ointments, salves, and lotions do wonders for first-degree burns, like sunburns, but they only complicate second- and third-degree burns. Burns are treated best by complete exposure to the air, but this can be done only in a controlled atmosphere such as in a hospital.

1-52. An electrical burn from a low voltage source usually covers only a small area of the skin, and can generally be easily recognized. First-aid treatment will consist of covering the burn with a bandage. A band-aid will usually be enough to protect it from infection. There is no first-aid treatment for internal tissue damage. Internal injuries of this type will usually be cured through the normal healing qualities of the body.

1-53. Chemical burns are not usually as crippling as burns from fire or electrical sources. This is true only if first-aid is promptly given. First-aid consists of washing the affected area vigorously with soap and plenty of water. If harmful chemicals should get in someone's eyes, they should be flushed out immediately with a stream of water from any available source.

1-54. Fire Protection and Prevention

1-55. The best fire protection program consists of adequate prevention. It's as simple as that.

1-56. Good housekeeping is the first line of defense in a well-organized fire prevention program. Accumulations of rubbish, waste, and trash are all prime sources of fire. In addition, concentrations of flammable or explosive gases and vapors are other sources of dangerous and destructive fire, all of which are preventable.

1-57. Fires are divided into three basic groups as an aid to firefighters in selecting the correct procedure to follow in the event of a fire.

CLASS A - These are usually wood, paper, or rag fires. This type of fire can be effectively brought under control by water, through its cooling and quenching effect.

CLASS B - These are fires which are fed by gasoline and other fuels, solvents, and greases. These fires have to be smothered if they are to be controlled. The only effective way to fight them is to eliminate the air by blanketing the flames.

CLASS C - This type of fire occurs in electrical equipment and presents an additional hazard to firefighters. If a conducting agent, such as water is used, the electricity will travel through it and shock the person who is trying to extinguish the blaze. Therefore, the extinguishing agents must be nonconductors which rely principally on a smothering action.

1-58. Presently in use are eight different types of extinguishers that range from a simple water bucket to the more complicated foam-dispensing type. The types of fire extinguishers and the classes of fires against which they are used are as follows:

| TYPE OF EXTINGUISHER | CLASS OF FIRE |
|---|---|
| Water bucket | A |
| Water tank with hand pump | A |
| Antifreeze (Calcium choloride or potassium carbonate and other salts) | A |
| Soda acid (Sodium bicarbonate) | A |
| Loaded stream (Fire hose) | A |
| Chemical reaction foam (Carbonic acid) | A and B |
| Vaporizing liquid (Chlorobromethane) | B and C |
| $CO_2$ (Carbon dioxide) | B and C |

## Chapter 2

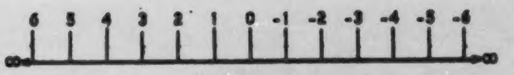
## ELECTRONIC MATHEMATICS

2-1. This chapter reviews the rules of signed numbers, discusses powers of 10, and explains how to convert any number to the standard power of 10 notation. Next, it covers how to multiply and divide, expand to powers, and extract roots of numbers expressed in powers of 10. A very important application of powers of 10 is the use of electronic prefixes to designate very small and very large numbers in electronic measurement. You must be able to convert standard prefixes to powers of 10, and powers of 10 to standard prefixes, and change either of these to numerical values. Finally, you will find a study of equations and an example of how mathematics is used in electronics.

### 2-2. Signed Numbers

2-3. A signed number expresses a quantity and a direction from a reference or starting point. The number represents the unit of measure; the sign shows the direction from this reference point. If all numbers in one direction from zero are positive, then all numbers in the opposite direction will be negative. If numbers above zero are positive, all numbers below zero will be negative. The absolute value of a negative number is the same as the corresponding positive number. A negative 1000 volts of electricity is quite as dangerous as a positive 1000 volts. So remember, the sign of the number only indicates a direction.

2-4. Electronic mathematics requires a knowledge of the rules for multiplying, dividing, adding, and subtracting signed numbers. These rules will be discussed and illustrated in the following paragraphs. To understand the idea of direction of numbers look at the number line below.



Starting at zero and moving to the left are numbers without signs. They are understood to be positive (+) numbers. To the right of zero are negative (-) numbers. This scale may be used to add and subtract. For example, add +4 to a -3. To do this, find -3 on the number scale and count 4 in a positive direction (to left). The answer is a positive one. Now, to subtract -4 from +3, start at +3 and count in a negative direction (to the right) 4 places. The answer is -1. There are also rules to guide you in performing the various operations.

2-5. Adding signed numbers. When adding numbers with like signs (+, +) (-, -), the answer retains the same sign. See the examples below:

$$\text{a.}\ \begin{array}{r} 3\\ +8\\ \hline 11\end{array}\qquad \text{b.}\ \begin{array}{r} 93\\ +7\\ \hline 100\end{array}\qquad \text{c.}\ \begin{array}{r} 8.3\\ +.4\\ \hline 8.7\end{array}$$

$$\text{d.}\ \begin{array}{r} -1\\ +-6\\ \hline -7\end{array}\qquad \text{e.}\ \begin{array}{r} -80\\ +-8\\ \hline -88\end{array}\qquad \text{f.}\ \begin{array}{r} -3.0\\ +-.7\\ \hline -3.7\end{array}$$

When adding numbers with unlike signs, disregard the signs. Subtract the smaller number from the larger and express the remainder with the sign of the larger number. See the examples below:

$$\text{a.}\ \begin{array}{r} -10\\ +\ 3\\ \hline -\ 7\end{array}\qquad \text{b.}\ \begin{array}{r} 170\\ +-70\\ \hline 100\end{array}\qquad \text{c.}\ \begin{array}{r} -8\\ +91\\ \hline 83\end{array}$$

The important things to remember are: Disregard the signs of the numbers, subtract the smaller number from the larger number, and express the remainder with the sign of the larger number.

2-6. Subtracting signed numbers. Subtraction is the reverse operation of addition. This means that a subtraction problem is solved by changing the sign of the number being subtracted and adding the two numbers. The following examples illustrate the process:

(The signs in parenthesis are reminders that the sign of the subtrahend must be changed)

$$\begin{array}{r} 6 \\ \underline{(-)3} \\ 3 \end{array} \qquad \begin{array}{r} -6 \\ \underline{(-)\ 3} \\ -9 \end{array} \qquad \begin{array}{r} -6 \\ \underline{(+)-3} \\ -3 \end{array}$$

$$\begin{array}{r} 3 \\ \underline{(-)6} \\ -3 \end{array} \qquad \begin{array}{r} -3 \\ \underline{(-)\ 6} \\ -9 \end{array} \qquad \begin{array}{r} -3 \\ \underline{(+)-6} \\ +3 \end{array}$$

If you know how to add signed numbers, subtraction is easy. All you do is change the sign of the number being subtracted and proceed as in addition.

2-7. Multiplying signed numbers. When multiplying signed numbers there are two rules to remember: 1) Like signs (+, +) (-, -) ALWAYS yield a POSITIVE answer when multiplied together. See the examples:

a. $3 \times 5 = 15$

b. $-3 \times -5 = 15$

c. $8 \times 5 = 40$

d. $-1 \times -6 = 6$

e. $-4 \times -10 = 40$

The second rule is: 2) Multiplying unlike signs (+, -) (-, +) ALWAYS yields a NEGATIVE answer. See the examples:

a. $-4 \times 5 = -20$

b. $8 \times -3 = -24$

c. $-3 \times 10 = -30$

d. $4 \times -8 = -32$

2-8. Dividing signed numbers is covered later on in this text where you will be dividing powers of 10.

2-9. Power of Ten

2-10. Definitions used in powers of 10 are as follows:

a. BASE NUMBER - The number to be multiplied by itself. In powers of 10 the base number is 10.

b. EXPONENT - The power of a number. The number of times a base number is multiplied by itself.

c. NUMERICAL COEFFICIENT - The number preceding the base number and exponent.

*numerical coefficient* → $4 \times 10^3$ ← *exponent*

↖ *base number*

Figure 2-1. Powers of Ten

2-11. When the base number 10 is expressed with an exponent, it is called a POWER OF TEN. This means that 10 is multiplied by itself the exponent number of times. For example:

$10^0 = 1$

$10^1 = 10$

$10^2 = 10 \times 10$ or $100$

$10^3 = 10 \times 10 \times 10$ or $1{,}000$

$10^4 = 10 \times 10 \times 10 \times 10$ or $10{,}000$

Listed below are more powers of 10:

$10^5 = 100,000$

$10^6 = 1,000,000$

$10^7 = 10,000,000$

$10^8 = 100,000,000$

$10^9 = 1,000,000,000$

$10^{10} = 10,000,000,000$

$10^{11} = 100,000,000,000$

$10^{12} = 1,000,000,000,000$

2-12. Notice that the number of zeros, in each case, equals the exponent. Notice also that the exponents are all positive. You will also work with negative exponents which designate fractional or decimal numbers. Some of these are listed as follows:

$1/10 = 0.1 = 10^{-1}$

$1/100 = 0.01 = 10^{-2}$

$1/1,000 = 0.001 = 10^{-3}$

$1/10,000 = 0.000\,1 = 10^{-4}$

$1/100,000 = 0.000\,01 = 10^{-5}$

$1/1,000,000 = 0.000\,001 = 10^{-6}$

Powers of 10 such as $10^{-3}$, $10^{-6}$, and $10^{-12}$ are common in electronics.

2-13. Powers of 10 are used in electronics because they:

a. Simplify calculations.

b. Provide a convenient method of expressing very large or very small numbers.

2-14. Any number can be expressed as a quantity between 1 and 10 multiplied by the proper power of 10. The standard method of conversion is to move the decimal point so that one digit is to the left of the decimal; then multiply this digit by the proper power of 10 so that the value of the number does not change. Here are some examples of numbers expressed in powers of 10, using a numerical coefficient:

$4,000 = 4 \times 10^3$

$435,000 = 4.35 \times 10^5$

$.002 = 2.0 \times 10^{-3}$

$0.000\,067\,3 = 6.73 \times 10^{-5}$

2-15. Before moving a decimal point, there are these two rules: 1) Moving the decimal point to the left will generate positive exponents, and 2) Moving the decimal point to the right will produce negative exponents. Now, let's analyze the steps involved in making conversions to powers of 10.

2-16. Converting ANY number to powers of 10 is done in three steps:

a. Move the decimal point left or right in order to get a numerical coefficient between 1 and 10.

b. Determine the POLARITY of the exponent by the direction the decimal point was moved.

c. Determine the value of the exponent. The exponent is equal to the number of places the decimal point was moved.

2-17. Conversion of numbers greater than 1. The number 300 is greater than 1; let's convert it to powers of 10 following the three steps.

a. Move the decimal point until you have a number between 1 and 10:

$300 = 3.00$

b. Determine the polarity of the exponent by the direction the decimal point was moved. In this case, LEFT (+).

$300 = 3 \times 10^{+}$

c. Determine the value of the exponent. The exponent is equal to the number of places the decimal point was moved. In this case, two places.

$$300 = 3 \times 10^{+2}$$

The answer to this example is: $300 = 3 \times 10^{2}$.

NOTE: The positive sign is not written because it is understood that all numbers are positive unless they are marked negative.

EXAMPLE: Convert 4,200 to powers of 10.

a. Convert the original number to a numerical coefficient between 1 and 10.

$$4{,}200 = 4.2$$

b. Determine the polarity of the exponent. The exponent will be positive because the decimal point was moved to the LEFT.

$$= 4.2 \times 10^{+}$$

c. Determine the value of the exponent. The exponent is 3 because the decimal point was moved three places to the LEFT.

$$= 4.2 \times 10^{3}$$

The answer to this example is

$$4{,}200 = 4.2 \times 10^{3}$$

2-18. By now you should see the similarity between the second and third steps in conversion. Moving the decimal point determines BOTH the polarity and magnitude of the exponent. Work the following problem and combine the second and third steps: Convert 830 to powers of 10.

a. Convert the original number to a numerical coefficient between 1 and 10.

$$830 = 8.3$$

b. Determine the polarity and value of the exponent. The decimal point was moved to the LEFT (+), two places, so:

$$830 = 8.3 \times 10^{2}$$

2-19. Combine all three steps and convert 216 to powers of 10.

Convert the original number to a numerical coefficient between 1 and 10 and determine the polarity and value of the exponent. The answer is:

$$216 = 2.16 \times 10^{2}$$

2-20. Conversion of numbers less than one is accomplished by following the steps listed in paragraphs 2-15 and 2-16. The only differences will be the direction the decimal point is moved to obtain the numerical coefficient, and the polarity of the exponent.

Example 1: Convert .018 to powers of 10.

$$.018 = 1.8 \times 10^{-2}$$

In example 1, the decimal point was moved two places to the right (-2) to get the numerical coefficient between 1 and 10. Moving the decimal point to the RIGHT will ALWAYS make the exponent negative (-); so the value of the original number is not changed. The farther to the right the decimal point moves, the larger the NEGATIVE exponent must be.

Example 2: Convert .000 004 2 to powers of 10.

$$.000\,004\,2 = 4.2 \times 10^{-6}$$

In example 2, the decimal point was moved six places to the RIGHT (-6) to get a numerical coefficient between 1 and 10.

Example 3: Convert .186 231 to powers of 10.

$$.186\,231 = 1.862\,31 \times 10^{-1}$$

In example 3, the decimal point was moved only one place to the RIGHT (-1) to get a numerical coefficient between 1 and 10.

**2-21.** For numbers already between 1 and 10, you do not move the decimal point at all. The exponent is ZERO (0). For example: 6.741 may be written as $6.741 \times 10^0$. Since $10^0=1$, the value of the number has not been changed. Four can be written as $4 \times 10^0$, and so forth.

**2-22.** MULTIPLICATION using powers of 10. When multiplying using powers of 10, there are four steps in solving ANY problem:

a. Convert the numbers to be multiplied to powers of 10.

b. Multiply the numerical coefficients.

c. ADD the exponents.

d. Express the answer's numerical coefficient between 1 and 10.

Example: Multiply 300 x 400 using powers of 10.

a. Convert the numbers to be multiplied to powers of 10.

$$(300) \times (400)$$

$$(3 \times 10^2) \times (4 \times 10^2)$$

b. Multiply the numerical coefficients.

$$(\underline{3} \times 10^2) \times (\underline{4} \times 10^2) = (\underline{3} \times \underline{4}) \times 10^2 \times 10^2$$

or $$= \underline{12} \times 10^2 \times 10^2$$

c. ADD the exponents.

$$12 \times 10^2 \times 10^2 = 12 \times 10^{(2+2)}$$

or $$= 12 \times 10^4$$

d. Express the answer's numerical coefficient (12 in this example) as a number between 1 and 10 times the correct power of 10.

$$12 \times 10^4 = 1.2 \times 10^4 \times 10^1$$

or $$1.2 \times 10^{(4+1)} = 1.2 \times 10^5$$

Finally, this example can be written:

$$300 \times 400 = 1.2 \times 10^5$$

**2-23.** Now work two more examples following the four steps.

Example 1: Multiply 36,000 x 500,000 using powers of 10.

a. Convert the numbers to be multiplied to powers of 10.

$$(36{,}000) \times (500{,}000)$$

$$(3.6 \times 10^4) \times (5 \times 10^5)$$

b. Multiply the numerical coefficients.

$$(\underline{3.6} \times 10^4) \times (\underline{5} \times 10^5) = (\underline{3.6} \times \underline{5}) \times 10^4 \times 10^5$$

or $$= \underline{18} \times 10^4 \times 10^5$$

c. ADD the exponents.

$$18 \times 10^4 \times 10^5 = 18 \times 10^{(4+5)}$$

or $$= 18 \times 10^9$$

d. Express the answer's numerical coefficient as a number between 1 and 10 times the correct power of 10.

$$18 \times 10^9 = 1.8 \times 10^{(9+1)}$$

or $$= 1.8 \times 10^{10}$$

NOTE: Again, the decimal point had to be moved one place to the LEFT (+1) to obtain the correct numerical coefficient. This +1 was added to 9.

Example 2: Solve using powers of 10, 12,000 x 160,000.

a. Convert the numbers to be multiplied to powers of 10.

$$(12{,}000) \times (160{,}000)$$

$$(1.2 \times 10^4) \times (1.6 \times 10^5)$$

b. Multiply the numerical coefficients.

$$(\underline{1.2}\times 10^4)\times(\underline{1.6}\times 10^5) = (\underline{1.2}\times \underline{1.6})\times 10^4\times 10^5$$

or $= \underline{1.92}\times 10^4\times 10^5$

c. ADD the exponents.

$$1.92\times 10^4\times 10^5 = 1.92\times 10^{(4+5)}$$

or $= 1.92\times 10^9$

d. The answer's numerical coefficient is already between 1 and 10.

2-24. In solving any multiplication problem using powers of 10, the same four steps are ALWAYS followed. Here are two examples where a number greater than 1 is multiplied by a number less than 1.

Example 1: Multiply using powers of 10, 200,000 x .045.

a. Convert the numbers to be multiplied to powers of 10.

$$(200{,}000)\times(.045)$$

$$(2\times 10^5)\times(4.5\times 10^{-2})$$

b. Multiply the numerical coefficients.

$$(\underline{2}\times 10^5)\times(\underline{4.5}\times 10^{-2}) = (\underline{2}\times\underline{4.5})\times 10^5\times 10^{-2}$$

or $= \underline{9}\times 10^5\times 10^{-2}$

c. ADD the exponents.

$$9\times 10^5\times 10^{-2} = 9\times 10^{5+(-2)}$$

or $= 9\times 10^3$

d. The numerical coefficient of the answer is already between 1 and 10. The exponents are signed numbers, and in step c you had to add two numbers with different signs. The rule used on this problem is: Adding a NEGATIVE number is, mathematically, the same as SUBTRACTING a POSITIVE number.

Example 2: Multiply using powers of 10, .000 5 x 2,000.

a. Convert the numbers to be multiplied to powers of 10.

$$(.0005)\times(2{,}000)$$

$$(5\times 10^{-4})\times(2\times 10^3)$$

b. Multiply the numerical coefficients.

$$(\underline{5}\times 10^{-4})\times(\underline{2}\times 10^3) = (\underline{5}\times\underline{2})\times 10^{-4}\times 10^3$$

or $= \underline{10}\times 10^{-4}\times 10^3$

c. ADD the exponents.

$$10\times 10^{-4}\times 10^3 = 10\times 10^{(-4+3)}$$

or $= 10\times 10^{-1}$

d. Express the answer's numerical coefficient as a number between 1 and 10 times the correct power of 10.

$$10\times 10^{-1} = 1\times 10^{(-1+1)}$$

or $= 1\times 10^0$

**REMEMBER:** Exponents are signed numbers and adding equal numbers of opposite sign will equal zero.

2-25. So far in your study of multiplying powers of 10 you have covered multiplying two numbers larger than one, and a number larger than one times a number less than one. Now work two examples of multiplying two numbers, both of which are less than one.

Example 1: Using powers of 10, multiply .015 x .000 02.

a. Convert the numbers to be multiplied to powers of 10.

$$(.015)\times(.000\,02)$$

$$(1.5\times 10^{-2})\times(2\times 10^{-5})$$

b. Multiply the numerical coefficients.

$$(\underline{1.5} \times 10^{-2}) \times (\underline{2} \times 10^{-5}) = (\underline{1.5} \times \underline{2}) \times 10^{-2} \times 10^{-5}$$

or $$= \underline{3} \times 10^{-2} \times 10^{-5}$$

c. ADD the exponents.

$$3 \times 10^{-2} \times 10^{-5} = 3 \times 10^{-2+(-5)}$$

or $$= 3 \times 10^{-7}$$

d. The answer's numerical coefficient is already between 1 and 10.

Example 2: Multiply .000 25 x .000 021 using powers of 10.

a. Convert the numbers to be multiplied to powers of 10.

$$(.000\,25) \times (.000\,021)$$

$$(2.5 \times 10^{-4}) \times (2.1 \times 10^{-5})$$

b. Multiply the numerical coefficients.

$$(\underline{2.5} \times 10^{-4}) \times (\underline{2.1} \times 10^{-5}) = (\underline{2.5} \times \underline{2.1}) \times 10^{-4} \times 10^{-5}$$

or $$= \underline{5.25} \times 10^{-4} \times 10^{-5}$$

c. ADD the exponents.

$$5.25 \times 10^{-4} \times 10^{-5} = 5.25 \times 10^{-4+(-5)}$$

or $$= 5.25 \times 10^{-9}$$

d. The answer's numerical coefficient is already between 1 and 10.

**2-26. DIVISION OF NUMBERS USING POWERS OF TEN.** The division of 6,000 by 300, can be mathematically expressed as:

$$\frac{6{,}000}{300}$$

The first step is to convert 6,000 to $6 \times 10^3$ and 300 to $3 \times 10^2$. Then, write the problem as:

$$\frac{6 \times 10^3}{3 \times 10^2}$$

The next step is to divide the numerical coefficient in the denominator into the numerical coefficient of the numerator. This part of the problem is written as:

$$\frac{6}{3} = 2$$

The next step for division is to subtract the exponent of 10 in the denominator from the exponent of 10 in the numerator:

$$\frac{10^3}{10^2} = 10^{3-2} = 10^1$$

Combine the two parts and the answer is:

$$= 2 \times 10^1$$

**2-27.** The basic rules for dividing:

a. Convert the number to be divided to powers of 10.

b. Divide the numerical coefficients.

c. Combine the exponents by subtraction, bring the denominator's exponent above the line, change its sign, and add it to the numerator's exponent.

d. Express the answer's numerical coefficient between 1 and 10 times the correct power of 10.

Example 1:

$$\frac{.006}{.03} = \frac{6 \times 10^{-3}}{3 \times 10^{-2}} = 2 \times 10^{-3-(-2)}$$

$$= 2 \times 10^{-3+2} = 2 \times 10^{-1}$$

Example 2:

$$\frac{.000\,005\,4}{.000\,09} = \frac{5.4 \times 10^{-6}}{9 \times 10^{-5}} = .6 \times 10^{-6-(-5)}$$

$$= .6 \times 10^{-6+5} = .6 \times 10^{-1}$$

$$= 6 \times 10^{-2}$$

Example 3:

$$\frac{80,000}{.000\,000\,2} = \frac{8 \times 10^{4}}{2 \times 10^{-7}} = 4 \times 10^{4-(-7)}$$

$$= 4 \times 10^{4+7} = 4 \times 10^{11}$$

Example 4:

$$\frac{.0008}{20,000,000} = \frac{8 \times 10^{-4}}{2 \times 10^{7}} = 4 \times 10^{-4-7}$$

$$= 4 \times 10^{-11}$$

Example 5:

$$\frac{1}{25} = \frac{1 \times 10^{0}}{2.5 \times 10^{1}} = .4 \times 10^{0-1}$$

$$= .4 \times 10^{-1} = 4 \times 10^{-2}$$

Example 6:

$$\frac{100}{1,000} = \frac{10^{2}}{10^{3}} = 10^{2-3} = 10^{-1} = 1 \times 10^{-1}$$

Example 7:

$$\frac{10^{4}}{40} = \frac{1 \times 10^{4}}{4 \times 10^{1}} = .25 \times 10^{4-1}$$

$$= .25 \times 10^{3} = 2.5 \times 10^{2}$$

2-28. The third rule for division states that you can also bring the denominator's exponent above the division line, change its sign, and add it to the numerator's exponent. Of course, the other three rules must still be followed. Solve an example problem using this other method of satisfying the third rule:

Example 1: 400,000/.05

a. First rule is to convert the numbers to be divided to powers of 10:

$$\frac{400,000}{.05} = \frac{4 \times 10^{5}}{5 \times 10^{-2}}$$

b. The second rule states that the numerical coefficients are divided as shown below:

$$\frac{4 \times 10^{5}}{5 \times 10^{-2}} = \frac{.8 \times 10^{5}}{10^{-2}}$$

c. Now, the third rule states, bring the exponent above the line, change its sign, and add:

$$\frac{.8 \times 10^{5}}{10^{-2}} = .8 \times 10^{5+(+2)}$$

or $$= .8 \times 10^{7}$$

d. Finally, the fourth rule for dividing powers of 10 says that the answer must be a number between 1 and 10 times the correct power of 10:

$$.8 \times 10^{7} = 8 \times 10^{7} \times 10^{-1}$$

or $$= 8 \times 10^{6}$$

2-29. Now solve some additional problems using this alternate method for dividing powers of 10:

Example 2: 8,000/.04

a. Convert the numbers to powers of 10:

$$\frac{8,000}{.04} = \frac{8 \times 10^{3}}{4 \times 10^{-2}}$$

b. Divide numerical coefficients:

$$\frac{8 \times 10^{3}}{4 \times 10^{-2}} = \frac{2 \times 10^{3}}{10^{-2}}$$

c. Bring the exponent above the line, change its sign, and add it to the numerator's exponent:

$$\frac{2 \times 10^{3}}{10^{-2}} = 2 \times 10^{3+(+2)}$$

or $$= 2 \times 10^{5}$$

d. Express the answer as a numerical coefficient between 1 and 10 times the correct power of 10. However, "$2 \times 10^5$" is already expressed correctly, so the fourth rule is satisfied.

Example 3: .000 09/450

a. Convert the numbers to power of 10:

$$\frac{.000\,09}{450} = \frac{9 \times 10^{-5}}{4.5 \times 10^{2}}$$

b. Divide numerical coefficients:

$$\frac{9 \times 10^{-5}}{4.5 \times 10^{2}} = \frac{2 \times 10^{-5}}{10^{2}}$$

c. Bring the exponent above the line, change its sign, and add:

$$\frac{2 \times 10^{-5}}{10^{2}} = 2 \times 10^{-5+(-2)}$$

or $= 2 \times 10^{-7}$

d. The answer is already expressed as required by the fourth rule.

Example 4: 21,000/.007

a. Convert to powers of 10:

$$\frac{21{,}000}{.007} = \frac{2.1 \times 10^{4}}{7 \times 10^{-3}}$$

b. Divide numerical coefficients:

$$\frac{2.1 \times 10^{4}}{7 \times 10^{-3}} = \frac{.3 \times 10^{4}}{10^{-3}}$$

c. Bring the exponent above the line, change its sign and add:

$$\frac{.3 \times 10^{4}}{10^{-3}} = .3 \times 10^{4+(+3)}$$

or $= .3 \times 10^{7}$

d. Express the answer's numerical coefficient as a number between 1 and 10 times the correct power of 10.

$$.3 \times 10^{7} = 3 \times 10^{7} \times 10^{-1}$$

or $= 3 \times 10^{6}$

Example 5: .000 006/.000 003

a. Convert to powers of 10:

$$\frac{.000\,006}{.000\,003} = \frac{6 \times 10^{-6}}{3 \times 10^{-6}}$$

b. Divide numerical coefficients:

$$\frac{6 \times 10^{-6}}{3 \times 10^{-6}} = \frac{2 \times 10^{-6}}{10^{-6}}$$

c. Bring above the line, change the sign, and add:

$$\frac{2 \times 10^{-6}}{10^{-6}} = 2 \times 10^{-6+(+6)}$$

or $= 2 \times 10^{0}$

d. Express the answer's numerical coefficient as a number between 1 and 10 times the correct power of 10. The answer is expressed correctly.

**2-30. ADDITION AND SUBTRACTION WITH POWERS OF TEN.** A basic rule in all addition and subtraction is that you can only combine LIKE quantities. In order to add or subtract numbers that contain powers of 10, it is necessary for the exponent of the 10 to be the same.

Example 1:

$$(6 \times 10^{3}) + (3 \times 10^{3}) = 9 \times 10^{3}$$

As shown by example 1, to add numbers with powers of 10, add the numerical coefficients and keep the same exponent of 10. If the exponents are not the same, change the exponents to make them alike before adding the numbers.

**Example 2:**

$$(90 \times 10^4) + (6 \times 10^5)$$

In order to add these numbers, change the exponents to the same value. To do this, you can change the 90 x $10^4$ to 9 x $10^5$. The exponents are now equal and you have the following problem.

$$(9 \times 10^5) + (6 \times 10^5) = 15 \times 10^5$$

Express the final answer as a number between 1 and 10 times the proper power of 10 by writing the answer as 1.5 x $10^6$.

**Examples:**

$$340{,}000 + 75{,}000 = (340 \times 10^3) + (75 \times 10^3)$$
$$= 415 \times 10^3 = 4.15 \times 10^5$$
$$.0036 + .0125 = (.36 \times 10^{-2}) + (1.25 \times 10^{-2})$$
$$= 1.61 \times 10^{-2}$$

2-31. To subtract numbers that contain powers of 10, the same principles apply as used in addition. The 10's must have the same exponent. The numerical coefficients are subtracted, but the same power of 10 is retained. The final answer should be expressed as a number between 1 and 10 times the proper power of 10.

**Examples:**

$$340{,}000 - 75{,}000 = (340 \times 10^3) - (75 \times 10^3)$$
$$= 265 \times 10^3 = 2.65 \times 10^5$$
$$.0125 - .0036 = (125 \times 10^{-4}) - (36 \times 10^{-4})$$
$$= 89 \times 10^{-4} = 8.9 \times 10^{-3}$$

2-32. To square a number containing a power of 10, first square the numerical coefficient and then multiply the exponent of 10 by 2.

**Examples:**

$$(3 \times 10^4)^2 = (3)^2 \times (10^4)^2 = 9 \times 10^8$$

$$(.006)^2 = (6 \times 10^{-3})^2 = 36 \times 10^{-6}$$
$$= 3.6 \times 10^{-5}$$

2-33. To cube a number, cube the numerical coefficient and then multiply the exponent of 10 by 3.

**Examples:**

$$(5 \times 10^2)^3 = (5)^3 \times (10^2)^3 = 125 \times 10^6$$
$$= 1.25 \times 10^8$$
$$(.003)^3 = (3 \times 10^{-3})^3 = 27 \times 10^{-9}$$
$$= 2.7 \times 10^{-8}$$

2-34. To take the square root of a number with a power of 10, first take the square root of the numerical coefficient and then divide the exponent of 10 by 2.

**Example 1:**

$$\sqrt{9 \times 10^4} = \sqrt{9} \times \sqrt{10^4}$$
$$= 3 \times 10^{4/2} = 3 \times 10^2$$

**Example 2:** Take the square root of $\sqrt{360 \times 10^5}$:

To extract the square root, the exponent must be an even number. To convert to an even power of 10, move the decimal one place. In this case, if the decimal is moved to the left one place, you would have:

$$\sqrt{36 \times 10^6} = 6 \times 10^3$$

The square root of 36 is 6, and the square root of $10^6$ is $10^3$. To take the square root of an exponent, divide the exponent by 2.

**Example 3:**

$$\sqrt{.0064} = \sqrt{64 \times 10^{-4}} = 8 \times 10^{-2}$$

Table 2-1

ELECTRONIC TERMS

| NUMBER | POWER OF TEN | PREFIX | SYMBOL |
|---|---|---|---|
| 1 000 000 000 000 | $10^{12}$ | tera | T |
| 1 000 000 000 | $10^{9}$ | giga | G |
| 1 000 000 | $10^{6}$ | mega | M |
| 1 000 | $10^{3}$ | kilo | k |
| 100 | $10^{2}$ | hecto | h |
| 10 | $10^{1}$ | deka | da |
| 0.1 | $10^{-1}$ | deci | d |
| 0.01 | $10^{-2}$ | centi | c |
| 0.001 | $10^{-3}$ | milli | m |
| 0.000 001 | $10^{-6}$ | micro | µ |
| 0.000 000 001 | $10^{-9}$ | nano | n |
| 0.000 000 000 001 | $10^{-12}$ | pico | p |

Table 2-2

PREFIX STUDY

| NUMBER | POWER OF TEN | PREFIX | SYMBOL |
|---|---|---|---|
| 1 000 000 | $10^{6}$ | mega | M |
| 1 000 | $10^{3}$ | kilo | k |
| 0.001 | $10^{-3}$ | milli | m |
| 0.000 001 | $10^{-6}$ | micro | µ |
| 0.000 000 000 001 | $10^{-12}$ | pico | p |

Example 4:

$$\sqrt{.0009 \times .0036} = \sqrt{9 \times 10^{-4} \times 36 \times 10^{-4}}$$
$$= \sqrt{324 \times 10^{-8}} = 18 \times 10^{-4}$$
$$= 1.8 \times 10^{-3}$$

## 2-35. Electronic Prefixes

2-36. You will become acquainted with the electrical terms resistance, voltage, and current in later lessons. Some other terms you will become acquainted with are inductance, capacitance, power, and frequency. These are all terms referring to electrical values. Since these electrical values range from much less than one to much greater than unity, specific prefixes and symbols are used to simplify expressing their values.

2-37. Electronic technicians use certain POWERS OF TEN so much that special "names" and "symbols" have come into use. The names are prefixed to the standard unit. For instance, a thousand is a very common multiple. The symbol for a thousand is k and its prefix is kilo.

2-38. One thousand volts is called 1 kilovolt and is expressed as 1 kV.

2-39. One thousand ohms is called 1 kilohm and is expressed as 1 kΩ.

2-40. Numbers along with their powers of 10, prefixes, and symbols are listed in table 2-1. This information will help you determine component values in the circuits you will study later.

2-41. Five of the prefixes listed in table 2-1 are worthy of your study at this time. They are listed in table 2-2.

2-42. Table 2-3 shows how the prefixes appear when presented on a number line. Note that $10^0$, or 1, is the units place, and can represent such units as ohms, amperes, volts, and watts. Moving LEFT from units you have POSITIVE exponents, and moving RIGHT from units you have NEGATIVE exponents. This is similar to the number line studied in paragraph 2-4.

Table 2-3

PREFIX SCALE

| Mega (M) | Kilo (k) | Units | Milli (m) | Micro (u) | Nano (n) | Pico (p) |
|---|---|---|---|---|---|---|
| $10^6$ | $10^3$ | $10^0$ | $10^{-3}$ | $10^{-6}$ | $10^{-9}$ | $10^{-12}$ |

2-43. Conversion to Prefixes. Changing any number to a prefix is actually changing the number to a specific power of 10, the power of the 10 that the prefix represents. This conversion is accomplished in the following three steps:

Step 1: Rewrite the prefix as the power of 10 it represents.

Step 2: Move the decimal point of the original number to equal the polarity and numerical value of the exponent.

Step 3: Express the answer using the prefix and the original unit of measure.

Here are some examples using these three steps.

Example 1: 6,000 volts = ? kilovolts.

Step 1: Rewrite the prefix as the power of 10 it represents.

$$6{,}000 \text{ volts} = ? \times 10^3 \text{ volts}$$

(Kilo represents $10^3$.)

Step 2: Move the decimal point of the original number to equal the polarity and numerical value of the exponent.

$$6{,}000 \text{ volts} = \underline{6.0} \times 10^3 \text{ volts}$$

(The exponent was positive 3, so the decimal point was moved LEFT (+) three places.)

Step 3: Express the answer using the prefix and the original unit of measure.

$$6 \times 10^3 \text{ volts} = 6 \text{ kilovolts}$$

or 6 kV using the symbols for kilo (k) and volt (V).

Example 2: 2 amperes = ? milliamperes, restated using symbols:

$$2\text{ A} = ?\text{ mA}$$

Step 1: Rewrite the prefix as the power of 10 it represents.

$$2\text{ A} = ? \times 10^{-3}\text{ A}$$

Step 2: Move the decimal point of the original number to equal the polarity and numerical value of the exponent.

$$2\text{ A} = \underline{2{,}000} \times 10^{-3}\text{ A}$$

(The exponent was negative 3 (-3), so the decimal point was moved RIGHT (-) three places.)

Step 3: Express the answer using the prefix and the original unit of measure.

$$2{,}000 \times 10^{-3}\text{ A} = 2{,}000 \text{ milliamperes,}$$

or 2,000 mA.

Example 3: .02 A = ? mA.

Step 1: Rewrite the prefix as the power of 10 it represents.

$$.02\text{ A} = ? \times 10^{-3}\text{ A}$$

Step 2: Move the decimal point of the original number to equal the polarity and numerical value of the exponent.

$$.02\text{ A} = \underline{20} \times 10^{-3}\text{ A}$$

(The exponent was again negative 3 (-3), so the decimal point of the original number was moved RIGHT (-) three places.)

Step 3: Express the answer using the prefix and the original unit of measure.

$$20 \times 10^{-3}\ \text{A} = 20 \text{ milliamperes, or } 20\ \text{mA}$$

**2-44. Converting from a prefix to units.** Any time a number with a prefix is changed back to units, you are really changing a number times a power of 10 to a number times $10^0$ (times 1). If a person walks a mile, stops and turns around, then walks back to where he started, he had to change directions. The decimal point starts at units ($10^0$) and moves LEFT or RIGHT when changing a number to powers of 10, and has to go in the opposite direction to change the power of 10 back to the original number. As an example, in changing 2,000 to $2 \times 10^3$, the decimal point has to move LEFT three places. To change $2 \times 10^3$ back to units ($10^0$), the decimal point has to move three places to the RIGHT. Writing this last statement mathematically:

$$2 \times 10^3 = 2{,}000 \times 10^0, \text{ or } 2{,}000$$

This whole idea can be simplified if you remember that units place equals $10^0$. What do you add to a positive 3 in order to get 0? You add a negative 3, naturally; $3 + (-3) = 0$; and polarities of exponents tell us the direction the decimal point is moved: LEFT (+) and RIGHT (-). Therefore, in the example the decimal point had to move three places to the RIGHT (-3) to cancel out the positive 3 exponent and get back to units.

Example 1: 200 milliamperes = ? amperes, or using symbols:

$$200\ \text{mA} = \underline{?}\ \text{A}$$

The prefix milli (m) stands for $10^{-3}$, and that amperes is units, or $10^0$. Rewriting this example substituting what you know:

$$200 \times 10^{-3}\ \text{A} = \underline{?} \times 10^0\ \text{A}$$

Looking at the exponent, you see a negative 3 (-3). What do you add to a negative 3 in order to get 0? You add a positive 3. OK, the decimal point has to be moved in the positive direction (LEFT) three places in order to cancel out the negative 3 exponent.

$$200 \times 10^{-3}\ \text{A} = .2 \times 10^0\ \text{A, or } .2\ \text{A}$$

Example 2: 20,000 uA = ? A.

The prefix micro (u) stands for $10^{-6}$, and A is units ($10^0$). Substituting this information, we have:

$$20{,}000 \times 10^{-6}\ \text{A} = \underline{?} \times 10^0\ \text{A}$$

The exponent here is negative 6 (-6), which means that the decimal point was moved six places to the RIGHT in order to get microamperes. In order to get back to the units ($10^0$) place, the decimal point has to move six places to the LEFT (+6), or $-6 + (6) = 0$. Now the example can be written:

$$20{,}000 \times 10^{-6}\ \text{A} = .02 \times 10^0\ \text{A or } .02\text{A}$$

Example 3: 56 k$\Omega$ = $\underline{?}$ $\Omega$. ($\Omega$ is the symbol for ohms.)

The prefix k, or kilo, stands for $10^3$ and $\Omega$ is units ($10^0$). Substitute this information:

$$56 \times 10^3\ \Omega = ? \times 10^0\ \Omega$$

The exponent is positive 3(+3). You want to return to 0; what do you add? You would add a negative 3 (-3). The decimal point has to move RIGHT three places (-3). Now you have:

$$56 \times 10^3\ \Omega = 56{,}000 \times 10^0\ \Omega, \text{ or } 56{,}000\ \Omega$$

2-45. Because prefixes represent frequently used powers of 10, they are convenient to use. As an example, kilo may be substituted for $10^3$ in the following:

$$5 \times 10^3 \text{ meters} = 5 \text{ kilometers, or } 5\ \text{km}$$

$$10 \times 10^3 \text{ watts} = 10 \text{ kilowatts, or } 10\ \text{kW}$$

$$38 \times 10^3 \text{ ohms} = 38 \text{ kilohms, or } 38\ \text{k}\Omega$$

Milli (m) is equal to $10^{-3}$. Now substitute milli for $10^{-3}$:

$5 \times 10^{-13}$ amperes = 5 milliamperes, or 5 mA

$430 \times 10^{-3}$ watts = 430 milliwatts, or 430 mW

$6 \times 10^{-3}$ meters = 6 millimeters, or 6 mm

2-46. Converting units to prefixes, prefixes to units, or even prefixes to prefixes, is accomplished by simply moving the DECIMAL POINT.

2-47. Equations

2-48. To successfully analyze and solve electronic problems requires the use of formulas which are expressed as equations. A review of the techniques involved in solving equations will provide the basis for solving electronic formulas.

2-49. An equation is a mathematical statement that two quantities are equal. The quantity to the left of the equal sign in the equation $7 + 1 = 5 + 3$ is equal to the quantity to the right of the equal sign. Think of it as a precision-balanced scale. The equation is balanced when you begin to work with it, and you must keep it in balance as you work toward a solution. You can add, subtract, multiply, divide, raise to powers, and extract roots within an equation, providing you do exactly the same thing to both sides of the equation.

2-50. Equations are solved through the use of axioms. An axiom is a truth or fact that is self-evident and needs no proof.

2-51. The axioms below can be applied to any equation without changing the equality:

AXIOM 1: Adding the SAME number to BOTH sides.

AXIOM 2: Subtracting the SAME number from BOTH sides.

AXIOM 3: Multiplying BOTH sides by the SAME number.

AXIOM 4: Dividing BOTH sides by the SAME number.

AXIOM 5: Terms equal to a third term are equal to each other.

AXIOM 6: Raising BOTH sides to the SAME power.

AXIOM 7: Taking the SAME root of BOTH sides.

2-52. Some applications of these axioms are:

Example 1: $X - 5 = 12$

To find the value of X, use axiom 1 and add 5 to each side of the equation:

$$X - 5 + 5 = 12 + 5$$

$$X = 17$$

Example 2:

$$X + 10 = 20$$

In this example, use axiom 2 and subtract 10 from each side of the equation:

$$X + 10 - 10 = 20 - 10$$

$$X = 10$$

Example: 3

$$\frac{X}{5} = 12$$

Use axiom 3 and multiply both sides of the equation by 5.

$$\frac{X}{5} \times 5 = 12 \times 5$$

$$\frac{X}{5} \times \frac{5}{1} = 12 \times 5$$

$$X = 60$$

Example 4: $5X = 85$

Divide each side of the equation by 5

$$\frac{5X}{5} = \frac{85}{5}$$

$$X = 17$$

Example 5: If $X = M$ and $Z = M$ then $X = Z$

Terms that are equal to the same term are equal to each other.

Example 6: $X = 5$

Both sides may be squared and the result is

$$X^2 = 5^2$$

or $$X^2 = 25$$

Example 7: $X^2 = 36$

Take the square root of both sides.

$$\sqrt{X^2} = \sqrt{36}$$

$$X = 6$$

2-53. Transposing Terms

2-54. When solving equations it is often helpful to rearrange some of the terms by moving them from one side of the equation to the other. This can be done if the sign of the term is changed. For example:

$13X - 15 = 11$ is the same as

$$13X = 11 + 15$$

Here, the -15 on the left side of the equation was moved to the right side. It was negative 15 on the left side; when it moved to the right side it became a positive 15. (This is the same as adding 15 to both sides of the equation).

To complete the solution

$$13X = 26$$

$$X = 2$$

Look at another example to be sure you understand the process.

$$13X - 8 = 11 - 6X$$

To solve this one, move the unknown term (-6X) to the left side and the known term to the right.

$$13X + 6X = 11 + 8$$

The -6X was moved to the left side and became +6X; the -8 was moved to the right side and became a +8.

The problem can be completed by combining terms and using the division axiom:

$$19X = 19$$

$$X = 1$$

2-55. Cancellation

2-56. If the same number, with the same sign, appears in both members, both may be removed by cancellation.

Suppose $5X - 7 + 5 = X - 7 + 9$

You can drop -7 from both members and have

$5X + 5 = X + 9$ (AXIOM 1)

$5X - X = 9 - 5$ (AXIOM 2)

$4X = 4$

$X = 1$ (AXIOM 4)

2-57. Changing Signs in an Equation

2-58. All signs in an equation can be changed by multiplying both sides of the equation by -1.

$$-8X + 40 = -2X - 10$$

Multiply by (-1):

$8X - 40 = 2X + 10$ (AXIOM 3)

2-59. Solution of Simple Equations

2-60. By the application of AXIOMS, transposition, and cancellation, the solution of equations becomes a series of easy steps.

Example 1:

Solve
$$\frac{3X}{4} = 27$$

$$3X = 27 \times 4 \qquad \text{(AXIOM 3)}$$

or
$$3X = 108$$

$$X = \frac{108}{3} \qquad \text{(AXIOM 4)}$$

$$X = 36$$

Example 2:

Solve
$$13 = 4Y - 7$$

$$13 + 7 = 4Y \qquad \text{(AXIOM 1)}$$

$$20 = 4Y$$

$$\frac{20}{4} = Y \qquad \text{(AXIOM 4)}$$

$$5 = Y$$

Once you have solved for the unknown, you can also check yourself by substituting your answer for the unknown in the original problem as shown below:

Example 1:
$$\frac{3X}{4} = 27$$

$$\frac{3 \times 36}{4} = 27$$

$$\frac{108}{4} = 27$$

$$27 = 27$$

Example 2:
$$13 = 4Y - 7$$

$$13 = (4 \times 5) - 7$$

$$13 = 20 - 7$$

$$13 = 13$$

BOTH answers check out correctly.

2-61. When working electronic equations, you may run into problems that contain fractions as well as unknowns. Take this problem as an example:

$$\frac{4Y}{3} - \frac{3}{2} = \frac{Y}{3} - 1$$

This problem contains three fractions. To remove the fractions, you must find the LOWEST COMMON DENOMINATOR. The lowest common denominator is a number that all of the divisors can be divided into evenly. In these three fractions the denominators are 3, 2, and 3. What would be the lowest number that these denominators can be divided into evenly. Wouldn't 6 be the lowest common denominator? Multiply all terms by 6 and see what happens.

Example 1:

$$6\left(\frac{4Y}{3}\right) - 6\left(\frac{3}{2}\right) = 6\left(\frac{Y}{3}\right) - 6(1)$$

$$2(4Y) - 3(3) = 2(Y) - 6$$

$$8Y - 9 = 2Y - 6$$

The fractions have been removed; 6 was the lowest common denominator. Now finish the example:

$$8Y - 9 = 2Y - 6$$

$$8Y = 2Y - 6 + 9 \qquad \text{(AXIOM 1)}$$

$$8Y = 2Y + 3$$

$$8Y - 2Y = 3 \qquad \text{(AXIOM 2)}$$

$$6Y = 3$$

$$Y = \frac{3}{6} \qquad \text{(AXIOM 4)}$$

$$Y = \frac{1}{2} \text{ or } .5$$

Check the answer:

$$8(.5) - 9 = 2(.5) - 6$$

$$4 - 9 = 1 - 6$$

$$-5 = -5$$

This is another example which contains fractions.

Example 2:

$$\frac{5}{2Y} + \frac{1}{2} = \frac{7Y - 1}{5Y}$$

The three denominators are, 2Y, 2, and 5Y.

Since the unknown, Y, is a part of two denominators, it must be part of the lowest common denominator.

The number 10 seems to be the lowest common denominator, including the Y, which gives 10Y as the lowest common denominator. Now multiply each term by 10Y and see if the fractions are removed.

$$10Y(\frac{5}{2Y}) + 10Y(\frac{1}{2}) = 10Y(\frac{7Y - 1}{5Y})$$

$$5(5) + 5Y(1) = 2(7Y - 1)$$

$$25 + 5Y = 14Y - 2$$

The remainder of the solution is:

$$25 + 5Y = 14Y - 2$$

$$25 + 5Y + 2 = 14Y \qquad \text{(AXIOM 1)}$$

$$27 = 14Y - 5Y \text{ (AXIOM 2)}$$

$$27 = 9Y$$

$$\frac{27}{9} = Y \qquad \text{(AXIOM 4)}$$

$$3 = Y$$

Check the answer by substituting 3 for Y:

$$25 + 5(3) = 14(3) - 2$$

$$25 + 15 = 42 - 2$$

$$40 = 40$$

Example 3:

$$\frac{5}{6} - \frac{1}{3X} = 0$$

Once more the problem must be changed to one with no fractions before proceeding, by finding the lowest common denominator. The two denominators are 6 and 3X; remember, if the unknown (X in this example) is part of any denominator, it must be a part of the lowest common denominator. What would be the lowest common denominator in this case? Well, 6 is the lowest number that the two denominators can be divided into evenly, but one denominator has an unknown, X. This means the lowest common denominator is 6X. So multiply all terms by 6X to remove the fractions.

$$\frac{5}{6} - \frac{1}{3X} = 0$$

$$6X(\frac{5}{6}) - 6X(\frac{1}{3X}) = 6X(0)$$

$$1X(5) - 2(1) = 0$$

$$5X - 2 = 0$$

Now solve for the unknown:

$$5X - 2 = 0$$

$$5X = 0 + 2 \qquad \text{(AXIOM 1)}$$

$$5X = 2$$

$$X = \frac{2}{5} \qquad \text{(AXIOM 4)}$$

Check the answer by substituting it for X IN THE ABOVE EQUATION:

$$5X - 2 = 0$$

$$5\left(\frac{2}{5}\right) - 2 = 0$$

$$0 = 0$$

2-62. Your work in electronics will involve many formulas that contain more than one unknown quantity. You must be able to rearrange these formulas to find any quantity in terms of the other quantities involved.

2-63. Given the equation $I = E/R$, you must be able to rearrange these terms to solve for E when given I and R, and solve for R when given I and E.

2-64. If R is the unknown, the first step is to move it to the left side of the equation. To do this, use axiom 3. If you multiply both sides of an equation by the same value, you do not change the equality of the equation. In this instance, multiply both sides by R. The problem will look like this:

$$I = \frac{E}{R}$$

$$IR = \frac{E}{R} \times R$$

Because R is in both the numerator and denominator on the right side, they cancel each other. Therefore,

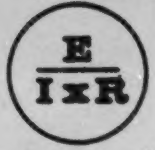
$$IR = E$$

This is still not the solution. You must finish with the R alone on the left side. To move the I to the right side, use axiom 4 and divide both sides by I as shown here:

$$\frac{IR}{I} = \frac{E}{I}$$

Now I is in both the numerator and denominator on the left side, so they cancel each other. The solution is:

$$R = \frac{E}{I}$$



REP 4-326

Figure 2-2

2-65. Next thing to solve for is the numerator E in the original equation, $I = E/R$. In this problem, multiply both sides by R:

$$I \times R = \frac{E}{R} \times R$$

$$IR = E$$

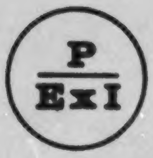
$$E = IR$$

2-66. The basic formula $I = E/R$ is not only the simplest formula used in electronics, it is also the most commonly used. What the equation actually states is that current (I) is equal to voltage (E) divided by resistance (R). When given any two of the three quantities, you can solve for the third.

2-67. CONVERSION BY RULE OF THUMB. As shown in figure 2-2, if you put your thumb over the unknown quantity, the mathematical process to follow is clearly indicated. For example, if you want the equation for E, cover the E with your thumb. The mathematical process to find E is then clearly shown; its IxR. If I is the unknown, cover it with your thumb to get E/R (E divided by R). If R is the unknown, cover the R to get E/I (E divided by I).

2-68. The rule-of-thumb is the shortest possible route to the solution. You can use either method, but you should find the rule-of-thumb process the quickest. It is important for you to learn how to find an unknown.

2-69. Another formula or equation which is frequently used in electronics is $P = EI$. As you may have already suspected, this formula also readily adapts itself to the rule-of-thumb method. That is, if it is



REP 4-327

Figure 2-3

arranged as shown in figure 2-3, you can find the unknown by covering it with your thumb and then performing the indicated mathematical process. If P is the unknown, it can be found by multiplying E x I. If E is the unknown, you can find it by dividing P by I. If I is unknown, divide P by E.

2-70. The next type of equation is no more difficult than the other equations. The most important thing to remember is to apply whatever axiom is necessary to get the unknown by itself on the left side of the equation in the final solution.

Given the equation $A/B = C/D$, solve for A.

In order to leave A by itself on the left side, multiply both sides by B.

$$B \times \frac{A}{B} = \frac{C}{D} \times B$$

The Bs on the left side cancel each other. Therefore,

$$A = \frac{CB}{D}$$

2-71. Start with the same equation and solve for B. This problem involves a process known as CROSS MULTIPLICATION. In cross multiplication, multiply the numerator on one side by the denominator on the other side. Do this for both sides. It works like this when solving for B:

$$\frac{A}{B} = \frac{C}{D}$$

Cross multiplying both numerators and denominators results in the expression:

$$BC = AD$$

To move the C, divide both sides by C:

$$\frac{BC}{C} = \frac{AD}{C}$$

$$B = \frac{AD}{C}$$

2-72. Regardless of which side has the unknown denominator, the process is the same. Cross multiply to get rid of the fraction, and then divide to leave the unknown by itself.

2-73. Given the equation $2\pi fCX_c = 1$, solve for f. Divide both sides by everything on the left - except the f. Then:

$$\frac{2\pi fCS_c}{2\pi CX_c} = \frac{1}{2\pi CX_c}$$

On the left side everything will cancel out - except the f. Therefore:

$$f = \frac{1}{2\pi CX_c}$$

2-74. In direct current circuits, the electronic technician is concerned with three values: voltage, current, and resistance.

2-75. The rule used to compute electrical values is known as Ohm's Law. As stated, "The current in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance." Hence, $I = E/R$ where:

E = Voltage-measured in volts (V)

I = Current-measured in amperes (A)

R = Resistance-measured in ohms (Ω)

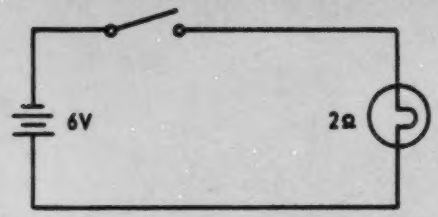


Figure 2-4 REP4-328

2-76. Assume the circuit shown in figure 2-4 is a railroad lantern. It consists of a 6 volt battery, a switch, and a lamp with a resistance of 2 ohms. The problem is to find the current when the switch is closed. I is equal to E divided by R or:

$$I = \frac{E}{R}$$

Substitute the values for E and R. Then:

$$I = \frac{6 \text{ volts}}{2 \text{ ohms}}$$

or $$I = 3 \text{ amperes}$$

2-77. All of the values in the circuit are known. Use the formula for practice to prove each value. Solve for R. The formula is:

$$R = \frac{E}{I}$$

Substituting values:

$$R = \frac{6V}{3A}$$

or $$R = 2\Omega$$

To solve for E, the formula is:

$$E = I \times R$$

THEREFORE, $$E = 3\text{ A} \times 2\Omega$$

or $$E = 6\text{ V}$$

2-78. The three forms of Ohm's Law are:

**Resistance:** $R=E/I$, the answer is expressed in ohms.

**Current:** $I=E/R$, the answer is expressed in amperes.

**Voltage:** $E=I\times R$, the answer is expressed in volts.

# NOTES

## Chapter 3

## PRINCIPLES OF DC

3-1. All the effects of electricity can be explained and predicted by assuming the existence of a tiny particle called the electron. Using the electron theory, scientists have been able to make predictions and discoveries which seemed impossible only a few years ago.

3-2. This entire study of electricity is based on the electron theory. The purpose of this study is for you to learn the theory of electricity, what it does, and how it does it. You will use this information in studying various electronic devices, how they work, and how to repair them. The electron theory will apply in this study to such things as batteries, lamps, generators, motors, and circuits leading to radio, radar, television, and other equipments.

### 3-3. Structure of Matter

3-4. The electron theory assumes that all electrical and electronic effects are due to the movement of electrons from place to place. Before working with electricity and finding out what can cause the electrons to move from place to place, knowledge of the electron itself is necessary. Because the electron is a part of the atom, understanding the atomic structure of MATTER is the starting point.

3-5. By definition, MATTER is anything that occupies space and has weight or mass. This means, of course, that everything is matter. Paper, wood, cloth, air, metal, and water are all examples of matter. Matter exists in three states: SOLIDS, LIQUIDS, and GASES. These are called STATES OF MATTER.

A piece of iron is an example of matter in a SOLID STATE.

Water is an example of matter in a LIQUID STATE.

Air is an example of matter in a GASEOUS STATE.

3-6. Matter can be further classified into ELEMENTS, MIXTURES, and COMPOUNDS. An ELEMENT is matter that cannot be broken down by chemical means. The combination of two or more elements with NO chemical interaction results in a MIXTURE. COMPOUNDS are combinations of elements which DO interact chemically; the elements lose their original identity, but may be obtained again through chemical processes.

3-7. SODIUM and CHLORINE are elements. When properly combined, these two elements form a compound commonly known as table salt.

3-8. The HYDROGEN and OXYGEN gases are elements. By combining these two gases, the compound water results.

3-9. A single drop of water is a very small amount. Spray this same drop through a tiny nozzle under high pressure and the droplets become too small to see individually, but each is still water. The smallest possible amount of water is called a MOLECULE of water. The water molecule can then be broken into its basic elements, hydrogen and oxygen.

3-10. A MOLECULE is defined as the smallest particle of an element or a compound which can exist in a free state and still be identified as that element or compound. An ATOM is the smallest particle of an element which still retains the characteristics of the element.

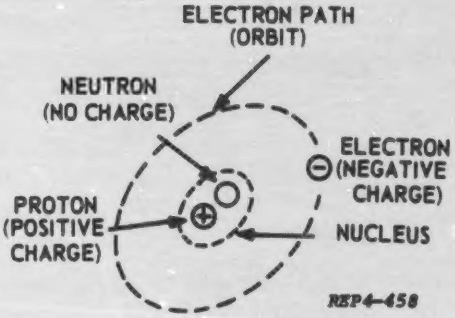


Figure 3-1

3-11. A simple atom is shown in figure 3-1. Breaking this atom down reveals the presence of several subparticles. These include the ELECTRON, PROTON, and NEUTRON. The center part of the atom is called the NUCLEUS and contains the PROTON and the NEUTRON.

3-12. The proton is represented by a circle with a plus sign to indicate it has a positive electrical charge. The neutron is neutral (has no charge), and is represented by a circle with no sign. The electron is a small particle whirling around the outside of the nucleus and is shown as a circle with a minus sign to indicate it has a negative electrical charge. The track which the electron travels around the nucleus is referred to as an energy level, orbit, or shell.

3-13. A hydrogen atom is shown in figure 3-2. It is the simplest atom, consisting of one proton in the nucleus, and one electron in orbit. Since the two opposite charges (+ and -) cancel each other, the entire atom itself is electrically neutral.

3-14. A carbon atom is shown in figure 3-3. It contains the same particles as the hydrogen atom, but in different quantities. The carbon atom contains six protons and six neutrons in the nucleus, and six negative electrons in orbit in two shells or energy levels. The charges cancel each other so the atom is electrically neutral.

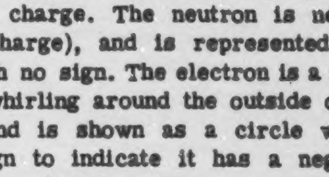


Figure 3-2

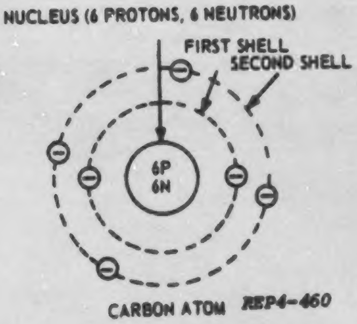


Figure 3-3

3-15. The difference between the atoms is that they contain different numbers of the same particles. An atom is electrically neutral when it contains the same number of positive charges in the nucleus as it has negative charges in orbit. Most atoms are electrically neutral. If they are not neutral, they are called IONS.

3-16. An example of an ion is shown in figure 3-4. There are four protons in the nucleus, but only three electrons in orbit. The three negative charges do NOT cancel the four positive charges, so the atom is not neutral. It is an ION. Since it has a deficiency of electrons, it is called a POSITIVE ION.

3-17. Another example of an ion is shown in figure 3-5. Again, there are four protons, but now there are five electrons. Having an excess of electrons, it is called a NEGATIVE ION.

3-18. The atom in figure 3-4 lost one electron in order to become a positive ion. Likewise, the atom in figure 3-5 gained one electron to become a negative ion.

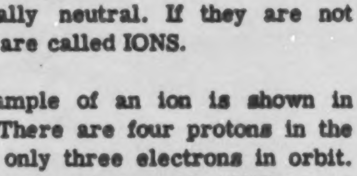


Figure 3-4

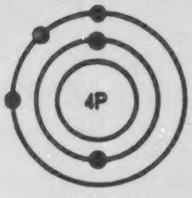


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Figure 3-5

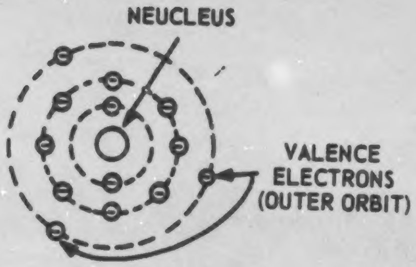

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Figure 3-6

3-19. In order for an atom to become an ion, it must lose or gain electrons in its outer orbit. This gain or loss is called ionization. Electrons in the outer orbit are called VALENCE ELECTRONS. See figure 3-6. "Valence" refers to the chemical behavior of the atom.

3-20. Hydrogen combines with oxygen to form the compound water. See figure 3-7. It is assumed that the valence electrons of the atoms share a common orbit. Valence, then, refers specifically to the ability of atoms to combine through chemical action. Four atoms of hydrogen combine to form two molecules of hydrogen and two atoms of oxygen combine to form one molecule of oxygen. When the compound is formed, the atoms of the elements combine to form two molecules of water: $2H_2 + O_2 = 2H_2O$.

3-21. Review

**MATTER** - Anything that occupies space and has weight or mass.

**STATES OF MATTER** - Solids, liquids, and gases.

**ELEMENT** - In chemistry, a substance that cannot be broken up into other substances by ordinary chemical changes.

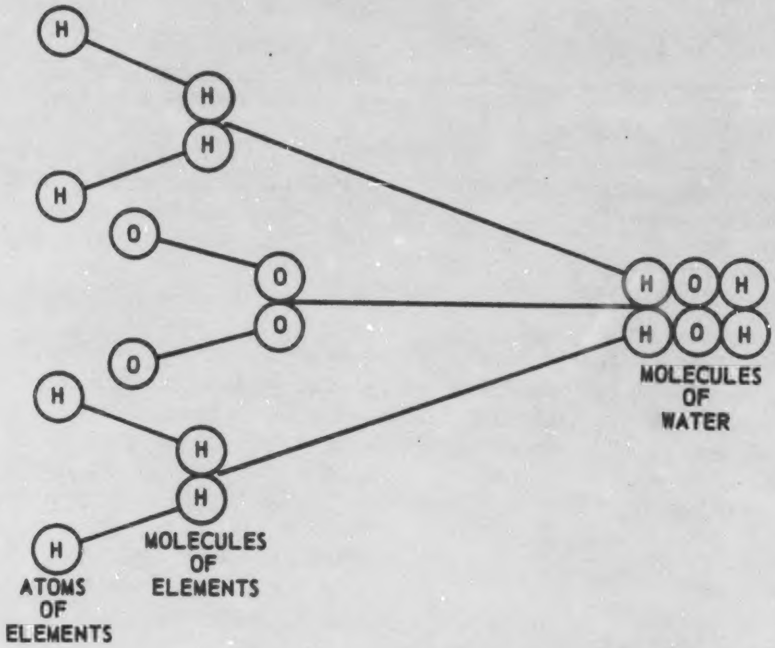

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Figure 3-7

ATOM - The smallest particles into which an element can be divided.

NUCLEUS - The positively-charged central part of an atom.

NEUTRON - A neutral particle found in the nucleus.

PROTON - A positively-charged particle found in the nucleus.

ELECTRON - A negatively-charged particle which is in orbit around the nucleus.

ION - An atom that is not neutral.

POSITIVE ION - An atom which has a deficiency of (lost) electrons.

NEGATIVE ION - An atom which has an excess of (gained) electrons.

VALENCE ELECTRONS - Electrons in the outer orbit of an atom.

### 3-22. Conductors, Semiconductors, and Insulators

3-23. In this study of electronics, the association of matter and electricity is important. Since every electronic device is constructed of parts made from ordinary matter, the effects of electricity on matter must be well understood. As a means of accomplishing this, all elements of which matter is made may be placed into one of three categories: CONDUCTORS, SEMICONDUCTORS, and INSULATORS, depending on their ability to conduct an electric current. Conductors are elements such as silver, copper, gold, and aluminum, which conduct electricity very readily. Insulators oppose the conduction of electricity. All matter between these two extremes may be called semiconductors.

3-24. The electron theory states that all matter is composed of atoms and the atoms are composed of smaller particles called protons, electrons, and neutrons. The electrons orbit the nucleus which contains the protons and neutrons. It is the valence electrons that we are most concerned with in electronics. These are the electrons which are easiest to break loose from their parent atom. Normally, conductors have three or less valence electrons; insulators have five or more valence electrons; and semiconductors usually have four valence electrons.

3-25. The electrical conductivity of matter is dependent upon the atomic structure of the material from which the conductor is made. In any solid material such as copper, the atoms which make up the molecular structure are bound firmly together. At room temperature copper will contain a considerable amount of heat energy. Since heat energy is one method of removing electrons from their orbits, copper will contain many FREE ELECTRONS that can move from atom to atom.

3-26. When not under the influence of an external force, these electrons move in a haphazard manner within the conductor. This movement is equal in all directions so that electrons are not lost or gained by any part of the conductor.

3-27. When controlled by an external force, the electrons move generally in the same direction. The effect of this movement is felt almost instantly from one end of the conductor to the other. The electron movement is called an ELECTRIC CURRENT.

3-28. Some metals are better conductors of electricity than others. Silver, copper, gold, and aluminum are materials with many free electrons and make good conductors. Silver is the best conductor, followed by copper, gold, and aluminum. Copper is used more often than silver because of cost. Aluminum is used where weight is a major consideration, such as in high tension power lines, with long spans between supports. Gold is used when oxidation or corrosion is a consideration and good conductivity is required. The ability of a conductor to handle current also depends upon its physical dimensions. Conductors may be in the form of bars, tubes, or sheets, but are usually in the form of wire.

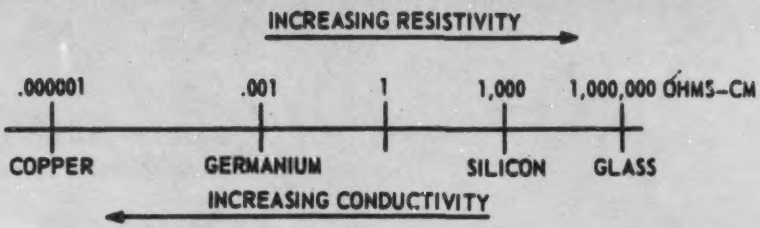

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Figure 3-8

3-29. Nonconductors have few free electrons. These materials are called INSULATORS. Some examples of this type material are rubber, plastic, enamel, glass, dry wood, and mica. Just as there are no perfect conductors, neither is there a perfect insulator.

3-30. Some materials are neither good conductors nor good insulators, since their electrical characteristics fall between those of conductors and insulators. These in-between materials are classified as SEMICONDUCTORS. Germanium and silicon are two common semiconductors used in solid state devices.

3-31. Another way to look at this subject is from the resistivity point of view. Opposition to the flow of electrical current due to the type of material used is called RESISTIVITY. The resistivity of a material is inversely proportional to the number of free electrons available in a unit specimen of the material. The reciprocal of resistivity is conductivity, the ability of material to conduct electric current. Refer to figure 3-8 for a better understanding of the relationship of the materials which we have discussed.

### 3-32. Review

A conductor is any material that has many free electrons. Silver, copper, gold, and aluminum are examples. Copper is the most commonly used.

An INSULATOR is a material with few free electrons. Rubber, mica, glass, dry wood, and plastics are examples of good insulators.

SEMICONDUCTORS are materials with some free elections. Their resistivity and conductivity fall between insulators and conductors. Germanium and silicon are examples of semiconductors used in transistors.

### 3-33. Charged Bodies

3-34. The study of electrostatics is the study of electricity at rest. The forces between electric particles can be observed experimentally and measured. Fundamental laws that govern these forces have been derived and stated. This text discusses these laws, the conduction and induction process of charging an object, the distribution of charges on an object, and the definition of a COULOMB.

3-35. The LAW OF ELECTRIC CHARGES states:

LIKE CHARGES REPEL EACH OTHER.

UNLIKE CHARGES ATTRACT EACH OTHER.

3-36. An ELECTRIC CHARGE may be any one of the following:

An ELECTRON - a unit negative charge.

A PROTON - a unit positive charge.

A GROUP OF ELECTRONS - equal in negative charge to the number of electrons present.

A GROUP OF PROTONS - equal in positive charge to the number of protons in the group.

A NEGATIVE ION - an atom that has gained electrons.

A POSITIVE ION - an atom that has lost electrons. It has a positive charge equal to the number of electrons lost.

3-37. The electron is the basic unit of electric charge. An atom with an equal number of electrons and protons is NEUTRAL. We assume the number of protons remains constant. The free electrons, however, may move and carry their negative charge from atom to atom. The atom they leave becomes POSITIVELY charged and the atom they join becomes NEGATIVELY charged. This can be seen in figure 3-9. An atom becomes charged when it either gains (or loses) electrons. Substances contain atoms, therefore substances may also become charged.

3-38. An example: If electrons are taken away from a pith ball, the entire ball becomes positively charged. Add electrons and the pith ball becomes negatively charged. A substance is always in one of three electrical conditions: positive, negative, or neutral.

3-39. Charged substances either attract or repel each other. Consider a pith ball that is positively charged. Place it near one which is negatively charged, and they will attract each other. Figure 3-10. If the balls are free to move, they will come closer together. If the balls are not free to move, the force of attraction still exists between them due to their unlike charges.

3-40. The attraction is caused by the ELECTRIC FIELD between the excess protons in one pith ball and excess electrons

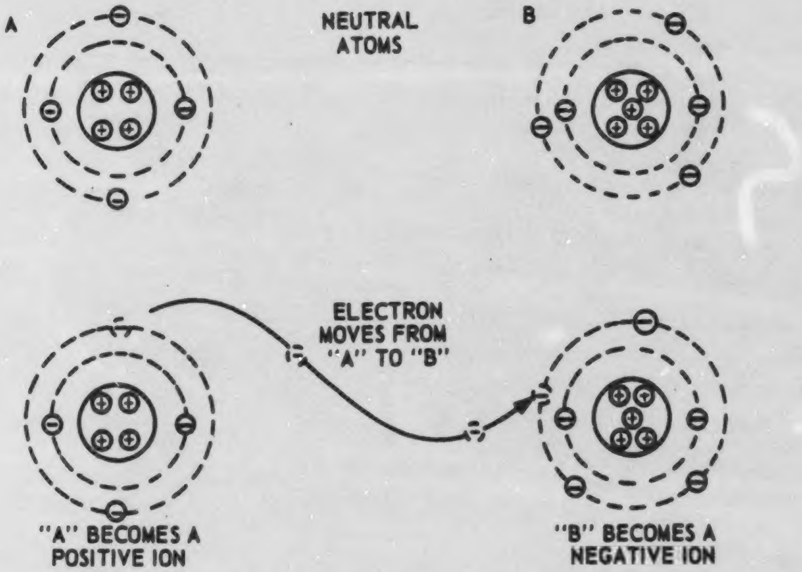
A
NEUTRAL ATOMS
B
ELECTRON MOVES FROM "A" TO "B"
"A" BECOMES A POSITIVE ION
"B" BECOMES A NEGATIVE ION

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Figure 3-9

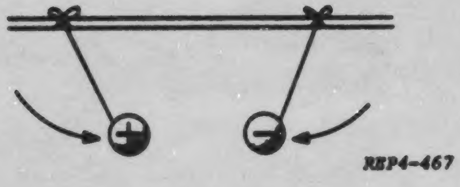


Figure 3-10

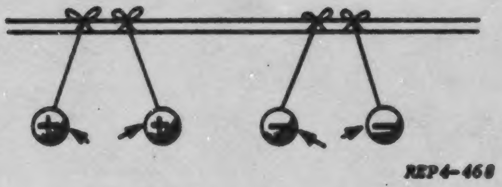


Figure 3-11

in the other pith ball. An electric field is composed of unseen lines of force which radiate in all directions.

3-41. Pith balls with the same charge repel each other as shown in figure 3-11.

3-42. COULOMB'S LAW OF CHARGED BODIES. A force of REPULSION always exists between LIKE CHARGES due to their electric fields. Thus, if an electron is placed close to another electron, they will repel each other without coming into contact. The force of this repulsion or attraction is related to the distance between the charged bodies. The force is directly proportional to the strength of the charges and inversely proportional to the square of the distance between the charges.

3-43. The unit of electrical charge is the COULOMB. One coulomb equals $6.28 \times 10^{18}$ electrons.

3-44. CHARGING AN OBJECT. Friction is one method of producing a static charge. Rub a glass rod with a piece of silk and friction produces a positive charge on the rod. Rub a rubber rod with a piece of cat's fur and friction produces a negative charge.

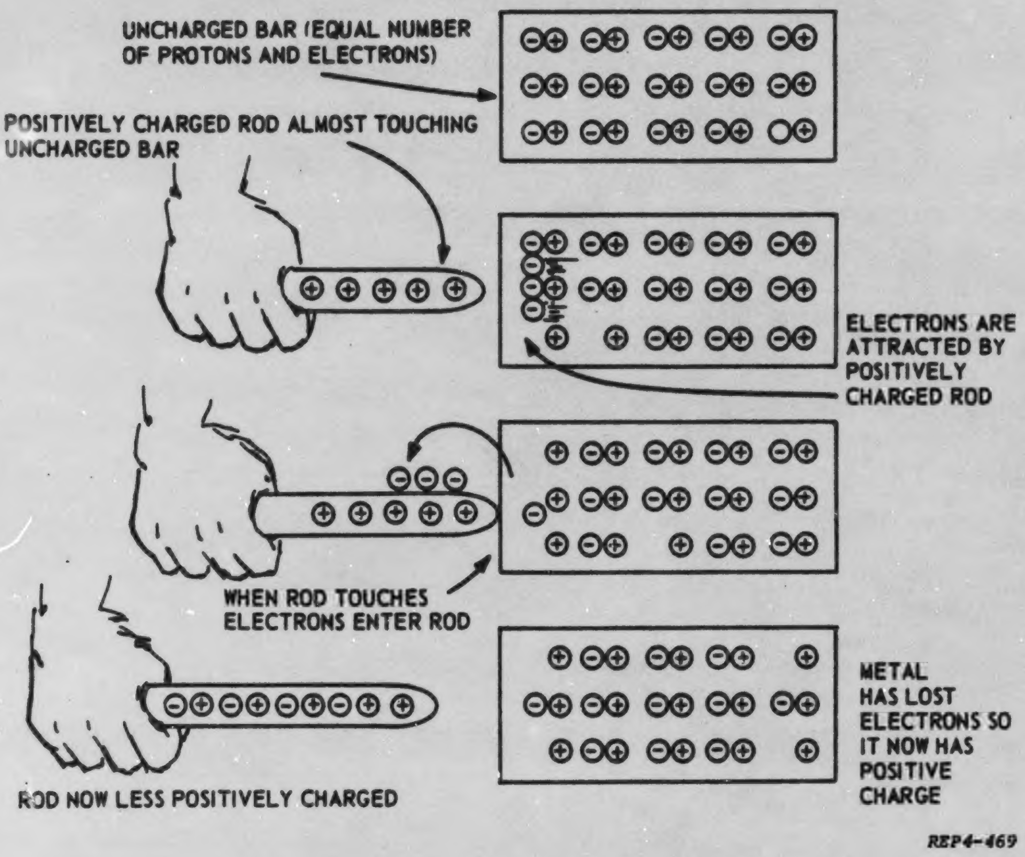

UNCHARGED BAR (EQUAL NUMBER OF PROTONS AND ELECTRONS)
POSITIVELY CHARGED ROD ALMOST TOUCHING UNCHARGED BAR
ELECTRONS ARE ATTRACTED BY POSITIVELY CHARGED ROD
WHEN ROD TOUCHES ELECTRONS ENTER ROD
METAL HAS LOST ELECTRONS SO IT NOW HAS POSITIVE CHARGE
ROD NOW LESS POSITIVELY CHARGED
REP4-469

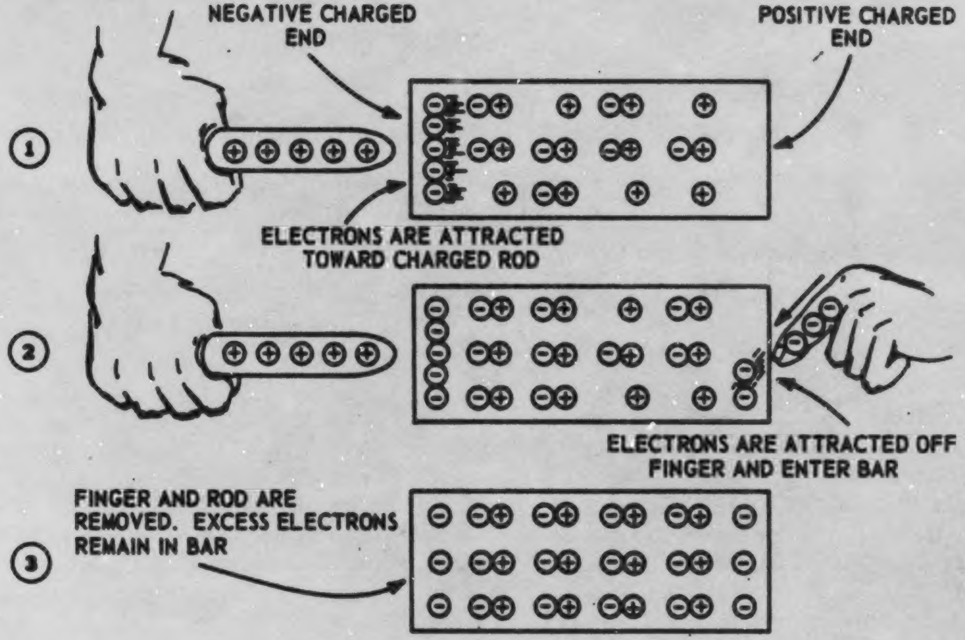
Figure 3-12

3-45. Another method of charging an object is through conduction. See figure 3-12. Touch a positively charged rod to an uncharged metal bar and the charge on the rod will attract electrons in the bar to the point of contact. Some of these electrons will leave the bar and enter the rod. The bar has become positively charged. A static charge has been transferred through actual contact. This is the CONDUCTION method of charging an object.

3-46. Another way to charge an object is through induction. Bring a positively charged rod near the bar (figure 3-13). Electrons in the bar are attracted to the point nearest the rod. Electrons accumulate at that point leaving a positive charge elsewhere on the bar. Allowing electrons from an outside source (your finger, for instance) to enter the positive end of the bar gives the bar a negative charge. The bar has become charged even though the rod did not touch it. This is known as the INDUCTION method of charging an object.

3-47. In one example, the object received a positive charge. In the other example, the object received a negative charge.

3-48. Methods of neutralizing a charge. Figure 3-14 shows the examples of static discharge between charged bodies; through a conductor, by actual contact, and through an arc.


NEGATIVE CHARGED END
POSITIVE CHARGED END
①
ELECTRONS ARE ATTRACTED TOWARD CHARGED ROD
②
ELECTRONS ARE ATTRACTED OFF FINGER AND ENTER BAR
FINGER AND ROD ARE REMOVED. EXCESS ELECTRONS REMAIN IN BAR
③

REP4-470

Figure 3-13

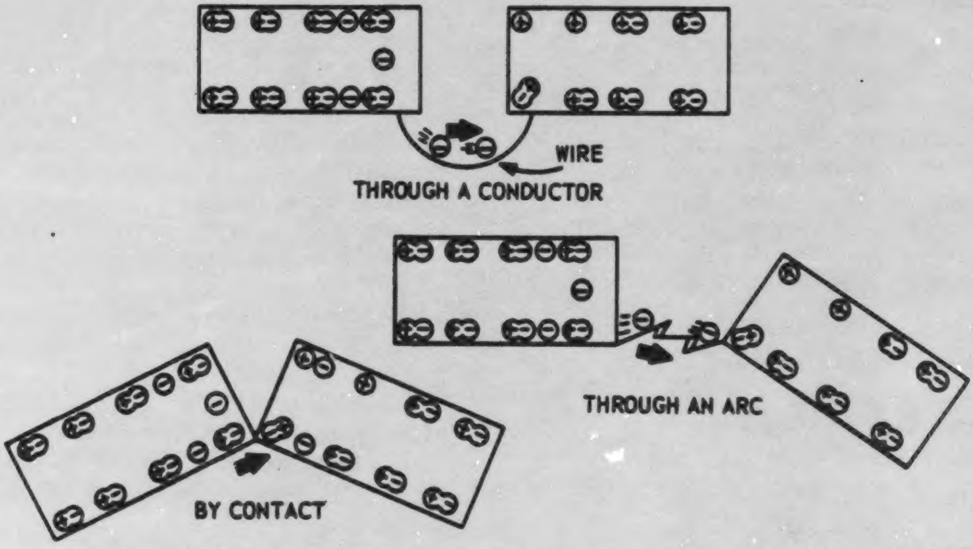


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Figure 3-14

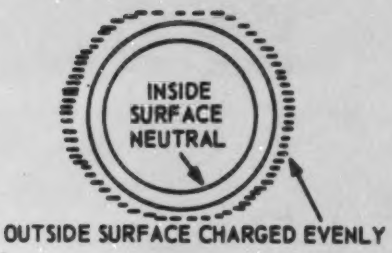
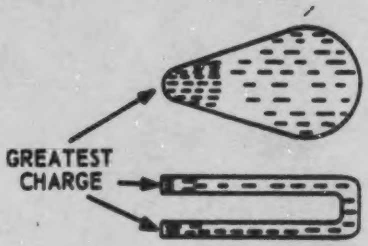


Figure 3-15 REP4-472



REP4-473

Figure 3-16

3-49. Distribution of Charges. A negative charge has been placed on the hollow metal sphere shown in figure 3-15. When the sphere is tested with an electrostatic detector, it is found that the charge has spread out evenly over the surface. This distribution is explained by the conductivity of the metal sphere, and the mutual repulsion of electrons. Although the sphere is made of conducting material, the entire charge is evenly distributed on the OUTSIDE surface. The inner surface contains little or no charge.

3-50. A negative charge placed on an object with an irregular shape is no longer evenly distributed. See figure 3-16. The charge will be concentrated at the points or sharpest curves of the object.

3-51. Review

3-52. Electrically, a body will be positive, negative, or neutral. Bodies with unlike charges attract each other. Bodies with like charges repel each other. The "coulomb" is equal to $6.28 \times 10^{18}$ electrons and is the basic unit of measure for electrical charge.

3-53. Friction, induction, and conduction are methods of charging an object. The charge is distributed evenly on the outside surface of a sphere. The charge is concentrated at the points of an irregularly shaped object.

3-54. Fundamentals of Direct Current

3-55. Previously a conductor was defined in terms of its atomic structure. It was stated that a good conductor is a material with many free electrons. The electric field around an electron causes it to repel other electrons without touching them. Now let's take a good conductor and pay particular attention to the free electrons in it.

3-56. A copper conductor has many free electrons. See figure 3-17. The free electrons are evenly distributed in the conductor and are moving about in a random manner.

3-57. If positively and negatively charged rods are placed as shown in figure 3-18, an electric field will exist between the ends of the conductor. The negatively charged rod will repel the electrons in the conductor while the positively charged rod attracts these electrons. The movement of the free electrons will no longer be totally random. There will be movement (drift) of free electrons toward the positive rod. Some electrons will enter the conductor from the negative rod and leave the conductor to enter the positive rod. This drift or movement of electrons we defined as current flow or electric current. The charge on the negative rod was used as a supply of electrons.

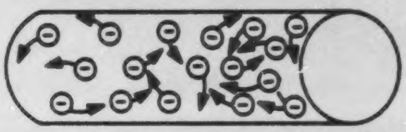


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Figure 3-17

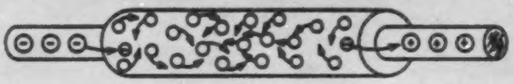

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Figure 3-18

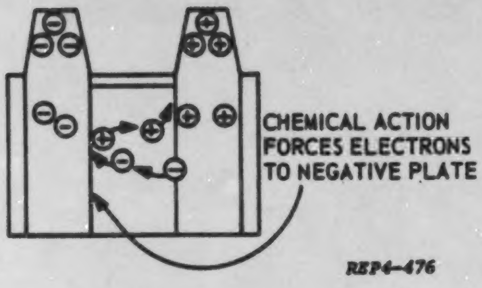


Figure 3-19

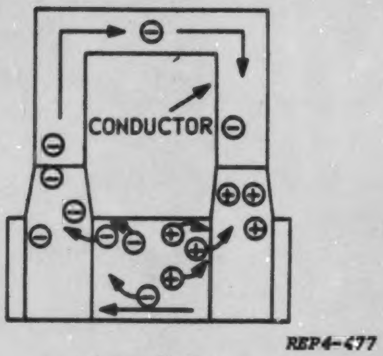


Figure 3-20

3-58. Take another example, this time using an automobile battery as our source of electrons. See figure 3-19. Chemical action inside the battery causes an excess of electrons at the negative terminal and a deficiency of electrons at the positive terminal.

3-59. If a conductor is connected between the terminals of the battery, the positive and negative forces cause the movement of electrons. The excess electrons at the negative terminal repel electrons and the deficiency of electrons at the positive terminal attracts electrons; an electron flow results and this electron flow is called an ELECTRIC CURRENT. Our battery in figure 3-20 has caused a current flow through the conductor.

3-60. This movement of electrons is a chain reaction that occurs almost simultaneously throughout the conductor. Try not to think of current flow in terms of an individual electron leaving the negative terminal moving through the conductor and back into the positive terminal. But think of current flow as the progressive movement of an electrical charge from one point to another point. For every electron which moved OUT from the negative terminal, an electron moved IN to the positive terminal.

3-61. When an electron leaves the negative terminal, it immediately repels a free electron already in the wire. See figure 3-21. This free electron repels another free electron, etc. A chain reaction takes place throughout the entire conductor. At nearly the same time that an electron was leaving the negative terminal, a free electron was pulled off the conductor by the positive terminal. The effect is almost instantaneous throughout the conductor. The effect of electron flow approaches the speed of light, approximately $300 \times 10^6$ meters per second.

3-62. We have now satisfied our statement that when the random movement of free electrons in a conductor is altered to cause the electrons to move generally in the same direction, electron flow results. The direction taken by the electrons in figure 3-21 is from the negative terminal to the positive terminal, through the conductor. Chemical action inside the battery causes electrons to move from the positive terminal to the negative terminal. This is the basis of the electron theory. Electrons always move from NEGATIVE to POSITIVE in the EXTERNAL circuit and from POSITIVE to NEGATIVE inside a voltage source.

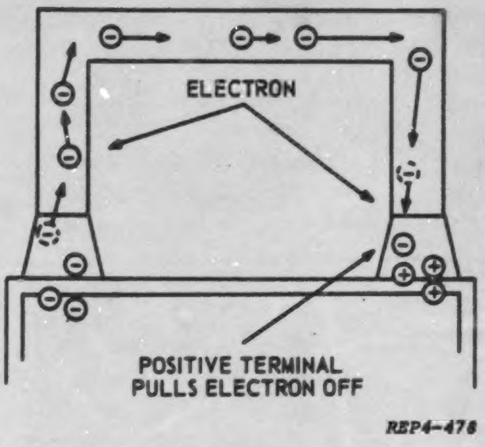


Figure 3-21

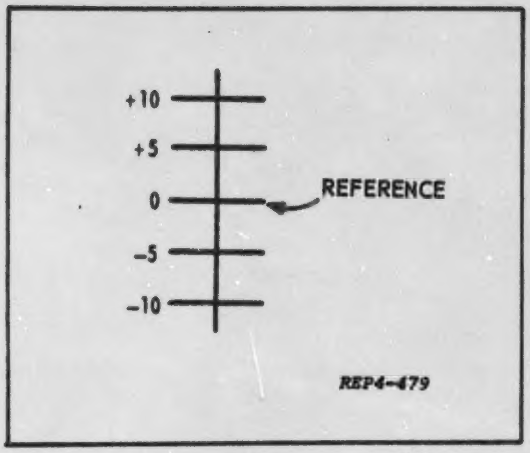


Figure 3-22

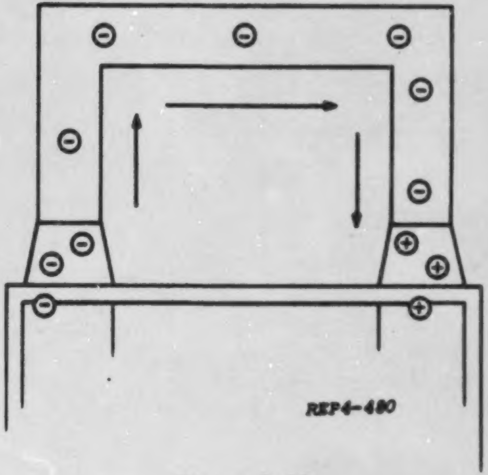


Figure 3-23

3-63. Note that the terms positive and negative are only relative. Using zero as a reference, as shown in figure 3-22, everything above zero is positive and everything below zero is negative with respect to the reference (zero). However, 5 below 0 is positive with respect to 10 below 0. Likewise, 5 above 0 is negative with respect to 10 above 0. The terms positive and negative may mean different things to different people, but to the electronics man, they mean either a shortage (positive) or an excess (negative) of electrons.

3-64. Since there is a difference in the quantity of electrons between the two battery terminals, we can say a potential difference exists. See figure 3-23. If a conductor is connected between the terminals, the excess electrons on the negative post flow toward the positive post where there is a shortage of electrons. In order to have electron flow, there must be a potential difference, a conductor, and a complete path (continuity). Electron flow can be measured as a quantity of electrons moving past a given point through a conductor in a given period of time.

3-65. The unit for electron flow is the AMPERE, and electron flow is called CURRENT. One ampere of current is flowing when 1 coulomb of electrons passes a point in a conductor in 1 second; 2 amperes flow when 2 coulombs pass per second, and so on. There are $6.28x10^{18}$ electrons in 1 COULOMB.

3-66. Ampere refers to the intensity of the current flow in a conductor. The standard symbol for current is "I." Electrical energy is required to move electrons from one point to another point. This electrical energy or potential difference is called ELECTROMOTIVE FORCE (EMF) and is the force (pressure) which causes current flow. (Consider EMF as an "Electron Moving Force.")

3-67. Electromotive Force is equal to the potential of the electrical charge and is expressed in volts. An electric charge, whether positive or negative, is a reserve of energy. This reserve energy is potential energy as long as it is not being used. The potential energy of a charge is equal to the amount of work done to create the charge and the unit of measure is the volt. The symbol used for the volt is "V" and the symbol used for EMF is "E". When two charges exist, the electromotive force between the charges is equal to the difference in potential of the two charges. Since the potential of each charge is expressed in volts, the difference in potential is also expressed in volts.

3-68. Voltage, or a difference in potential, exists between any two charges which are not equal. Even an uncharged body has a potential difference with respect to a charged body; it is positive with respect to a negative charge and negative with respect to a positive charge. A potential difference exists between two unequal positive charges or between two unequal negative charges. Thus, potential difference or voltage is purely relative and is not used to express the actual amount of charge but rather to compare one charge to another and indicate the electromotive force between the two charges being compared. Whenever two points of unequal charge are connected, as current flows from the more negative to the more positive charge. The greater the EMF or voltage between the charges, the greater the amount of current flow, when all other things remain constant.

3-69. Let's examine five common ways to generate an EMF. One method is to convert mechanical energy into electrical energy. Examples include the belt-driven alternator on your car, heavy diesel-driven generators used on railroad locomotives, and waterfall-driven turbines which impel the generators of hydroelectric installations. Chemical action (battery) is the second method of producing an EMF. The dry cell, like the one in your transistor radio, or a wet cell, like the one used in your car, produces an EMF by chemical action. A third method is the production of an EMF by the thermoelectric effect (heat) such as applying heat to two dissimilar metals. This principle has an important application as a temperature indicating device called a thermocouple. The photoelectric effect (light) is the fourth method used to produce an EMF. When light strikes a light-sensitive surface, called a photocathode, electrons will be emitted from the sensitive surface. A television camera pickup tube uses the photoelectric method of producing an EMF.

3-70. A fifth method of generating an EMF uses the piezoelectric effect. Certain ionic crystals generate a voltage whenever stress is applied to their surfaces. Thus, if a crystal of quartz is squeezed, a voltage will appear between two opposite surfaces of the crystal. If the force is reversed, the voltage will reverse polarity. Quartz or similar crystals can thus be used to convert mechanical energy into electrical energy. This phenomenon is called the PIEZOELECTRIC EFFECT. These crystals also have the ability to convert electrical energy into mechanical energy. A voltage impressed across the opposite surfaces of the crystal will cause it to expand or contract in response to the voltage applied.

3-71. To review what you have found out about current and voltage, consider some of the important facts you have studied:

A potential difference exists between points of unequal charge.

Current flow is always from negative to positive in the external circuit.

The ampere (A) is the practical unit of current.

The symbol for current is "I."

EMF (E) is the same as potential difference and is essential for current flow.

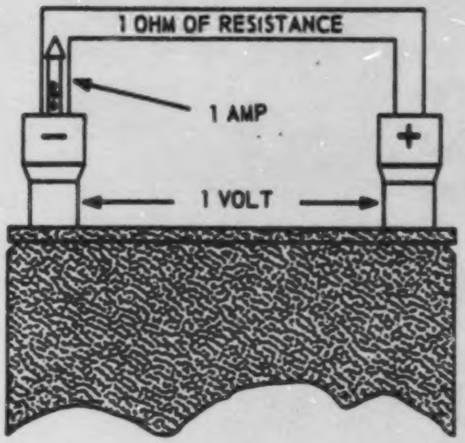
The volt (V) is the practical unit of EMF.

The symbol for voltage is "E."

Five common sources of EMF are mechanical, chemical, thermoelectric, photoelectric, and piezoelectric effects.

3-72. Resistance and Resistors

3-73. Another aspect of electronics is resistance. The opposition to current flow is known as resistance (R). The unit of measure of resistance is the OHM. The symbol used to represent the ohm is the Greek letter omega ($\Omega$). "R," for example, might equal $2\Omega$, $5\Omega$, $100\Omega$, etc., with the ohm being the practical unit of measure for resistance.



REP4-481

Figure 3-24.

3-74. How much opposition is 1 ohm of resistance? See figure 3-24. A conductor is connected between the negative and positive terminal of a battery. If 1 volt of pressure causes 1 ampere of current to flow, there is 1 ohm of resistance in the conductor.

3-75. Experiments prove that the same voltage applied to specimens of different materials having exactly the same physical dimensions will produce different values of electrical current. Similarly, if a fixed voltage is applied to specimens of the same material having different physical dimensions (length and diameter), the resulting electrical current will be different. On the basis of these effects, you can see that for a fixed voltage, the amount of current flowing through any material depends on the type of substance and the physical dimensions of the material. Further investigation has shown that the ratio of voltage to current for any type of material is a constant which depends on the material and its physical dimensions. Opposition to the movement of electrons through a substance is called RESISTANCE; it can be used to regulate both the movement of electrons and the forces acting on these electrons as they move from point to point within a conductor. Another factor that determines current flow is the temperature of the conductor.

Table 3-1

RESISTANCE COMPARISON

| SUBSTANCE | RELATIVE RESISTANCE |
|---|---|
| Silver (Standard) | 1.0 |
| Copper | 1.08 |
| Gold | 1.5 |
| Aluminum | 1.8 |
| Tungsten | 3.5 |
| Brass | 4.8 |
| Steel | 9.3 |
| Nichrome | 64.8 |

3-76. MATERIAL. The material of which an object is made affects its resistance. The ease with which different materials give up their valence electrons is the determining factor.

3-77. Table 3-1 compares the resistance of some common materials. Silver has the least resistance. Copper and aluminum are most often used for conductors due to cost factors. Nichrome has the highest resistance and is used in heater elements.

3-78. LENGTH. The next factor affecting the resistance of a conductor is its length. The longer the length, the greater the resistance. The shorter the length, the lower the resistance. An example: If a piece of copper wire 1,000 feet long and having a resistance of 6 ohms is increased to 2,000 feet, the resistance would increase to 12 ohms. THE RESISTANCE OF A CONDUCTOR IS DIRECTLY PROPORTIONAL TO ITS LENGTH.

3-79. DIAMETER OR CROSS-SECTIONAL AREA. Another factor affecting the resistance of a conductor is its cross-sectional area.

3-80. To understand what cross-sectional area means, imagine a wire cleanly cut across any part of its length. The area of the cut face of the wire is the cross-sectional area. The greater this area, the lower the resistance of the wire. The smaller this area, the higher the resistance of the wire.

3-81. An example: A piece of copper wire with a cross-sectional area of .1 square cm has a resistance of 6 ohms. Doubling the cross-sectional area to .2 square cm will decrease the resistance to 3 ohms, or one-half of its original value. Thus, the RESISTANCE OF A CONDUCTOR IS INVERSELY PROPORTIONAL TO ITS CROSS-SECTIONAL AREA.

3-82. TEMPERATURE. The final factor affecting the resistance of a conductor is its temperature. For most materials, the hotter the material, the more resistance it offers. The colder the material, the less resistance it offers. The amount of change of resistance per unit change in temperature is known as the TEMPERATURE COEFFICIENT. If an increase in temperature causes the resistance to increase, the material is said to have a POSITIVE TEMPERATURE COEFFICIENT. A material whose resistance decreases with an increase in temperature has a NEGATIVE TEMPERATURE COEFFICIENT.

3-83. Conductors are an important part of electrical equipment. A good conductor introduces very little resistance. However, a component to which the conductor is connected may offer a lot of resistance. One of these high-resistance components is called a RESISTOR.

3-84. A resistor is a physical device used to introduce a desired amount of opposition to current flow in an electrical circuit. The purpose of this resistor is to control the amount of current flow in that circuit. There is a certain amount of resistance in all electrical circuits. If this resistance isn't high enough to reduce the flow to the desired amount, then a resistor is added into the circuit.

3-85. Electronic equipments use a wide variety of resistors. Some have a fixed-resistance value and others are variable. Resistors are made of resistance wire, metal film or carbon. Wire-wound resistors are used to control large amounts of current. Wire-wound resistors are constructed by winding resistance wire on a porcelain base. The ends of the wire are attached to metal terminals. A coating is applied to the wire to protect it and conduct heat away. Figures 3-25, 3-26 and 3-27 illustrate some typical wire-wound resistors.

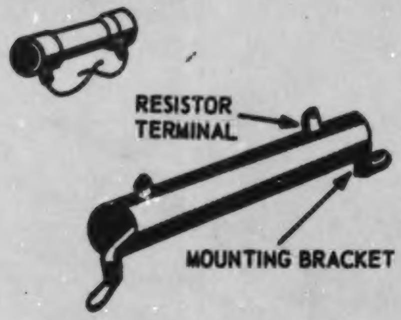


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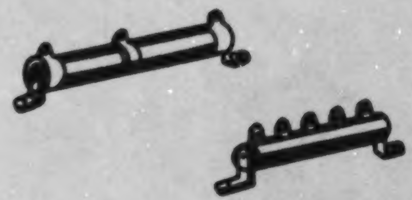
Figure 3-25



REP4-483

Figure 3-26

3-86. Wire-wound resistors may have fixed or adjustable taps which can be used to change the resistance value. See figure 3-26.

3-87. Precision wire-wound resistors, illustrated in figure 3-27, are used when the resistance value must be very accurate, such as in test instruments.

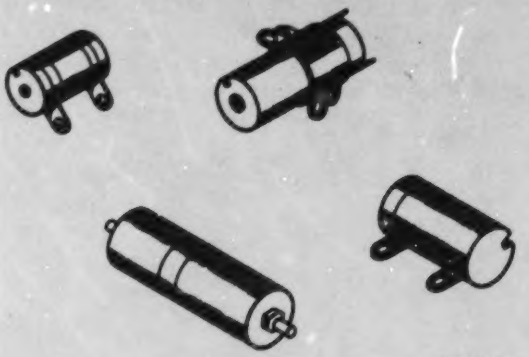


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Figure 3-27

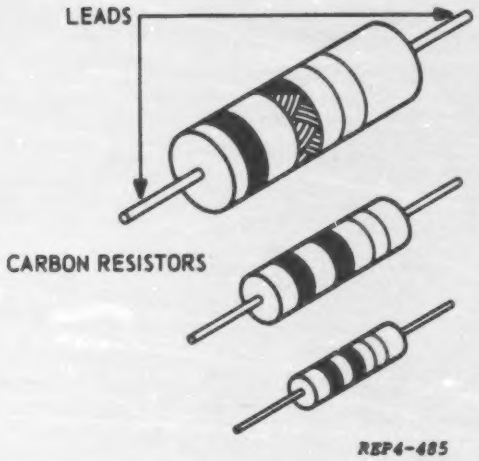


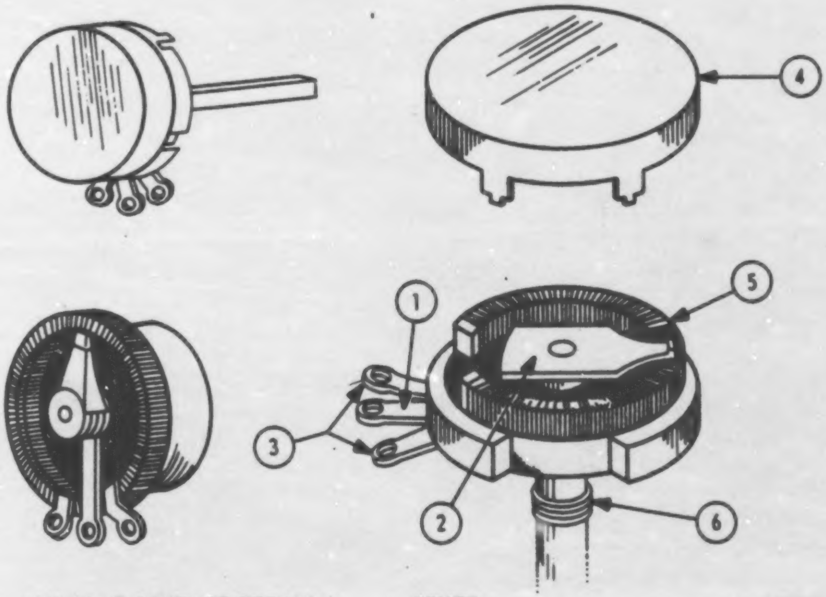
Figure 3-28

3-88. Carbon resistors are constructed of a rod of compressed graphite and a binding material. Wire leads are attached to each end of the rod. The rod is then covered with an insulating material. See figure 3-28.

3-89. Often a change in resistance is needed while the equipment is in operation. To do this, both carbon and wire-wound VARIABLE resistors have been designed: Wire-wound variable resistors, figure 3-29, are constructed by winding resistance wire on a porcelain or bakelite circular form. A contact arm, which can be adjusted to any position on the circular form, is connected to a rotating shaft. A lead connected to this movable contact arm is used with one or both of the end leads to vary the resistance.

3-90. For controlling small currents, carbon variable resistors are used, figure 3-30. They are constructed by depositing a carbon compound on a circular fiber disk. A variable sliding contact is connected to a rotating shaft and varies the resistance as the shaft is turned.

3-91. A variable resistor (figure 3-30) has an advantage over the adjustable resistor (figure 3-26). The value of the variable resistor may be changed while the equipment is in operation. Power must be turned off to change the value of the adjustable resistor.



1. VARIABLE CONTACT TERMINAL
2. VARIABLE SLIDER CONTACT
3. END TERMINALS
4. COVER
5. RESISTANCE ELEMENT
6. ROTATING SHAFT

Figure 3-29

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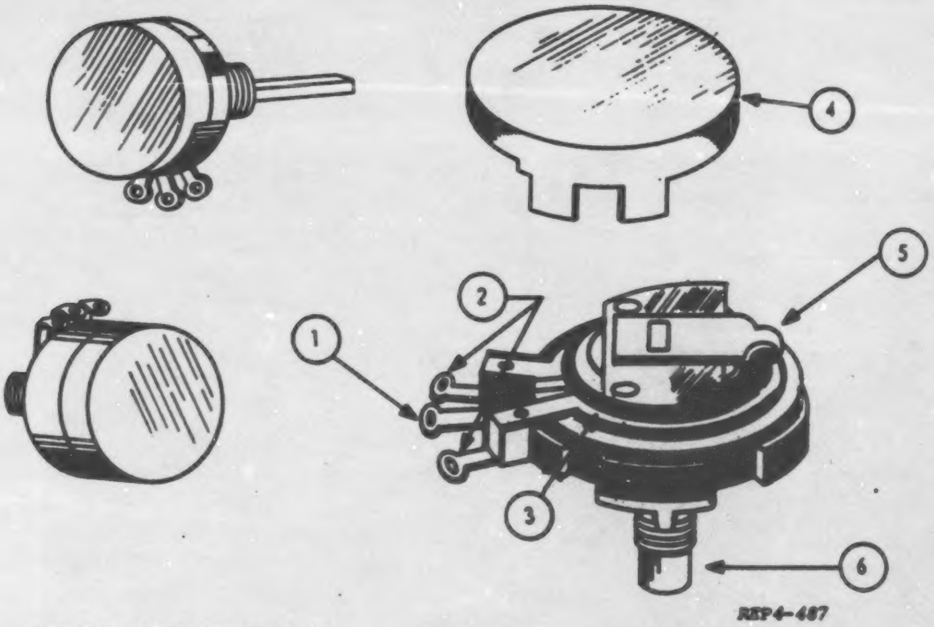

1. VARIABLE CONTACT TERMINAL
2. END TERMINAL
3. RESISTANCE ELEMENT
4. COVER
5. SLIDER CONTACT
6. ROTATING SHAFT

REP4-486

Figure 3-30

3-92. A SCHEMATIC is a circuit diagram which uses symbols to represent components. Figure 3-31 shows the schematic symbols for several resistors.

3-93. Basic Circuit Symbols and Components

3-94. You have seen that current flow is present when a conductor is connected between two charged bodies. In figure 3-32 the charged bodies are the two battery terminals.

3-95. When a conductor is placed between the terminals, current flows from negative to positive through the conductor. This is not a practical circuit. The conductor will shortout the battery and render it useless.

3-96. Some means must be employed in order to prevent this SHORTING-OUT of the power source. Any electronic device that offers resistance to current flow may be used. Obviously, a practical device must accomplish a specific job, such as ring a bell, or light a bulb.

3-97. There are three basic requirements of a practical circuit:

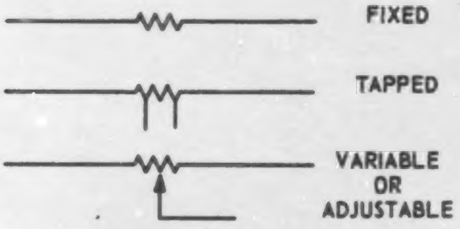

Figure 3-31 REP4-488

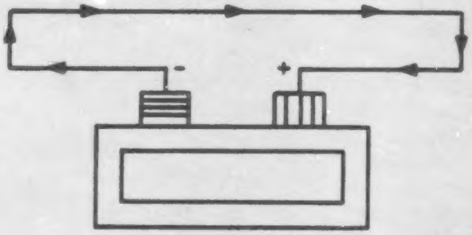

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Figure 3-32

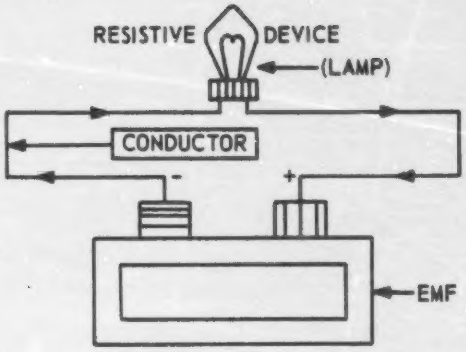

Figure 3-33

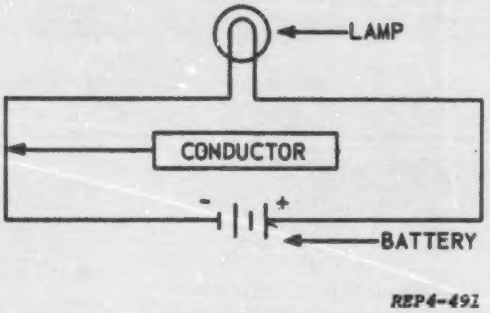

Figure 3-34

a. EMF source
b. Conductor
c. Resistor or power dissipating devices (bell, lamp, etc.).

Figure 3-33 shows a practical circuit which meets these requirements. The resistance of the lamp limits current flow and prevents a short circuit. At the same time, it will accomplish a desired function-creating light.

3-98. Figure 3-34 shows the schematic representation of figure 3-33. Note that symbols, rather than pictures are used to represent the electronic components. All electronic components have a symbol and you must be able to recognize the symbol and relate it to the proper component.

3-99. Let's take a look at a few basic circuit symbols. See figure 3-35.

**FIXED RESISTOR** - A set amount of opposition to current flow in a circuit. It is the most commonly used resistor and is available in a wide range of ohmic values.

**TAPPED RESISTOR** - One resistor can be used to obtain different amounts of opposition. Usually a wire-wound device.

**RHEOSTAT** - Type of variable resistor. Usually wire-wound and available in only low ohmic values. Carbon types are available in a wide range of values.

**POTENTIOMETER** - Type of variable resistor. Usually made of carbon and available in a wide range of ohmic values.

**BATTERY** - A device which converts chemical energy to electrical energy. In the single cell battery, the short line represents the negative terminal and the longer line represents the positive terminal. The multicell battery consists of two or more cells in series. The negative terminal of one cell is connected to the positive terminal of another cell and so on.

**GROUND** - Point in a circuit used as a common reference point from which voltages are measured. Voltages may be either positive or negative with respect to ground. You are probably familiar with the electrical ground on an automobile; the chassis is the common reference point.

**VOLTMETER** - Used to measure voltage in volts.

**AMMETER** - Used to measure current flow in amperes.

**OHMMETER** - Used to measure resistance in ohms.

**ROTATING MACHINES** - A generator is used to convert mechanical energy to electrical energy and a motor is used to convert electrical energy to mechanical energy.

**SWITCH** - Used as a circuit controlling device or simply a means of turning the circuit power ON and OFF. There are numerous switch combinations. The three illustrated here include the SPST

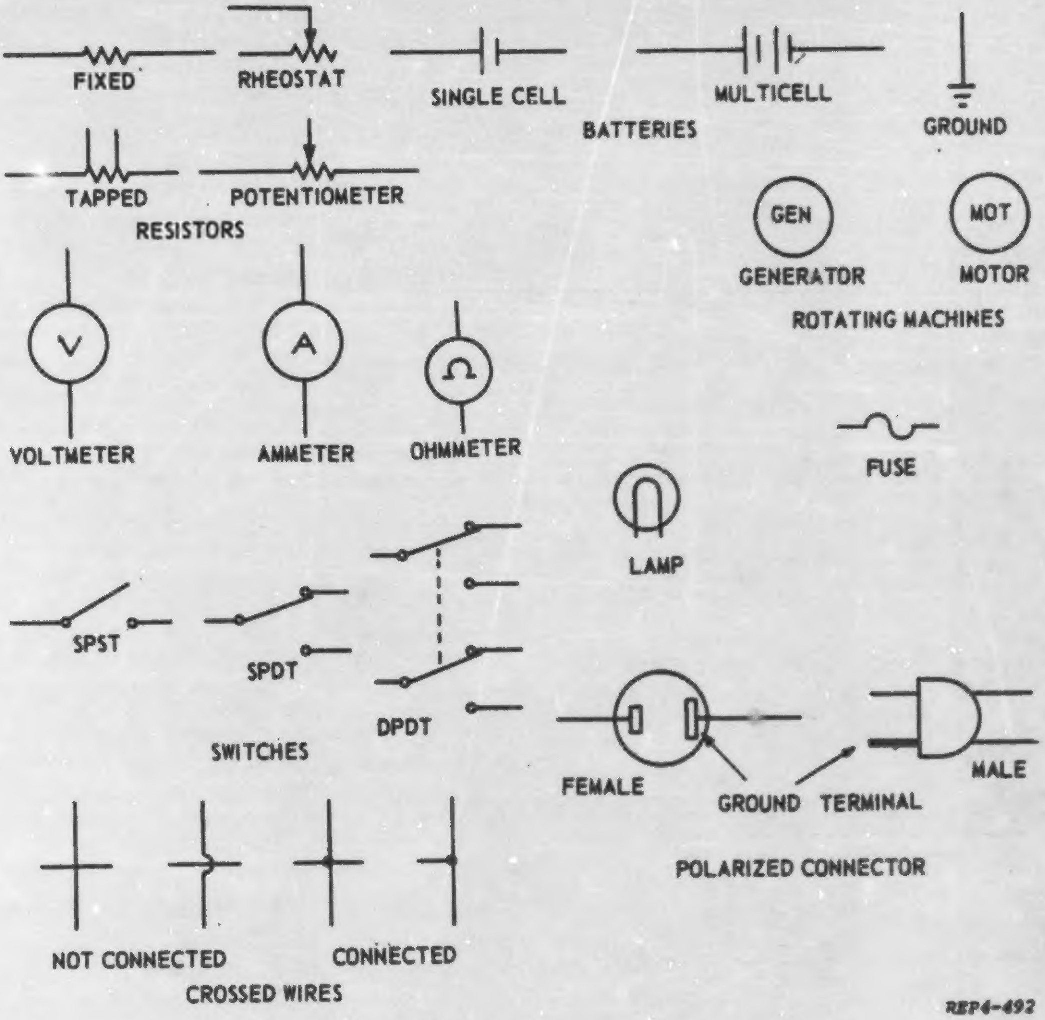

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Figure 3-35

(single-pole single-throw), SPDT (single-pole double-throw) and the DPDT (double-pole double-throw) switches.

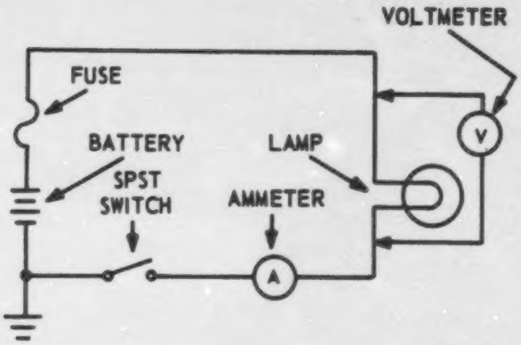
LAMP - Used as a load device or to provide a visual indication of current flow.

FUSE - Used as a protective device for the circuit in which it's located. Protects against excessive current flow.

CROSSED WIRES NOT CONNECTED - No dot at the junction where the wires cross.

CROSSED WIRES CONNECTED - Indicated by a dot at the junction where the wires cross or join.

POLARIZED CONNECTORS - Always used in DC (direct current) circuits. May be used in AC (alternating current) circuits. In either case the larger terminal on the male plug and the larger opening in the female plug is always the ground terminal.



REP4-493

Figure 3-36

3-100. Let's put some of these components into a circuit diagram. See figure 3-36.

3-101. Lamp. In this case, the purpose of the lamp is to provide light. Of course it also provides resistance to prevent a short circuit.

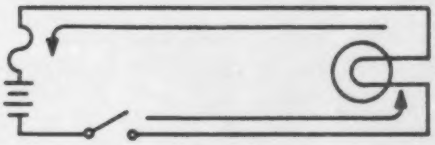


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Figure 3-37

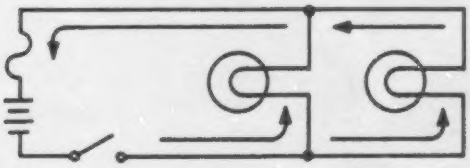

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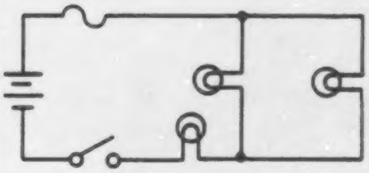
Figure 3-38



REP4-496

Figure 3-39

3-102. Fuse. A fuse is used as a protective device. The wires and the lamp in figure 3-36 can stand only so much current before burning out. Obviously, this is dangerous, and the fuse is used to protect against this condition. Its only job is to burn out when the circuit current becomes too high. If it burns out, it has done its job and should be replaced by another fuse of the same current rating.

3-103. Switch. The switch is used to let current flow or to shut it off. The switch is in the OFF position and has broken the path of current flow from the negative to the positive battery terminals. Switches are rated according to the voltage and current that they may safely interrupt. Care should be taken to use the proper switch.

3-104. Circuits are classified according to the way their components are arranged or connected. They may be classified as SERIES, PARALLEL, or SERIES-PARALLEL.

3-105. The circuits we have known in previous lessons have been SERIES circuits. We call them SERIES circuits because there is only one path for current flow. See figure 3-37.

3-106. Another type of circuit configuration is a PARALLEL circuit. In this type of circuit, there is more than one path for current flow. See figure 3-38.

3-107. A circuit using a combination of series and parallel is quite naturally called a SERIES-PARALLEL circuit. See figure 3-39.

3-108. Many electrical devices require a higher voltage or higher current than a single cell battery is able to furnish. Therefore, it is often necessary to connect several cells together. The manner in which cells are connected depends upon whether you want to increase voltage or current.

3-109. If greater voltage is needed, connect the cells in series. To connect cells in series, connect the negative terminal of each cell to the positive terminal of the following cell as shown in figure 3-40. The total voltage of the battery is then equal to the sum of the voltages of the separate cells. The same current must flow through each cell in succession. Therefore, the current that the battery can supply is limited to the current rating of a single cell. Thus, a battery composed of cells in series provides a higher voltage, but not a greater current capacity.

3-110. To obtain a greater current than one cell is able to supply, connect the cells in parallel. In this case, the total current available is the sum of the individual current ratings, since the current of one cell does not flow through the other cells. To connect cells in parallel, connect all positive terminals together as shown in figure 3-41.

3-111. The positive terminals of the cells will form the positive terminal of the battery, and the negative terminals of the cells, the negative terminal.

3-112. Each cell must have the same voltage, otherwise a cell with higher voltage will force current through the lower voltage cells and carry the greater part of the load. The output voltage of the battery made up of cells connected in parallel is, therefore, the same as that of a single cell.

3-113. Another method of arranging cells is to connect them in series strings which are in turn connected in parallel. In this method, groups of cells are connected in series and then the groups connected in parallel, as shown in figure 3-42. This connection provides both a greater voltage and a greater current capability.

3-114. The purpose of connecting cells in series is to obtain greater voltage.

3-115. The purpose of connecting cells in parallel is to obtain greater current capability.

3-116. The purpose of connecting series strings of cells in parallel is to obtain greater voltage and current.

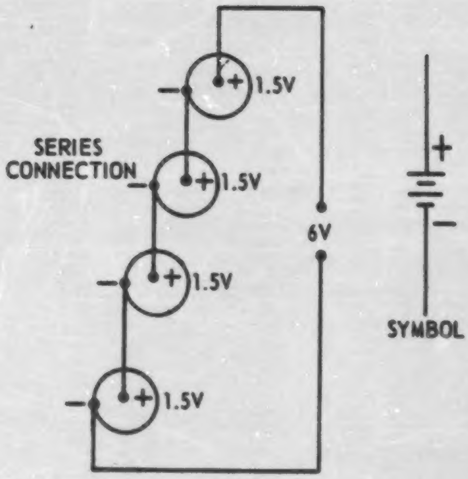
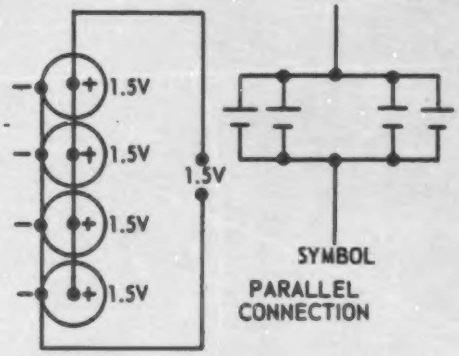


Figure 3-40 REP4-497



REP4-498

Figure 3-41

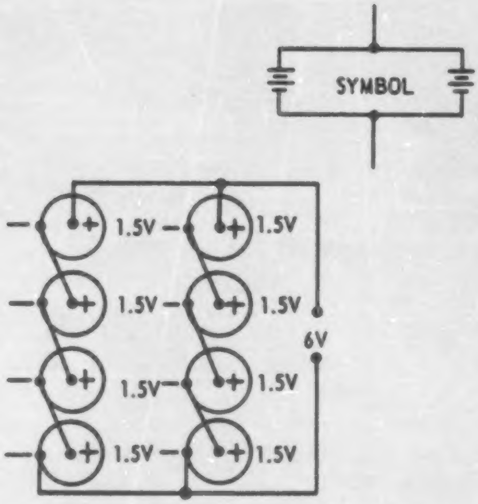
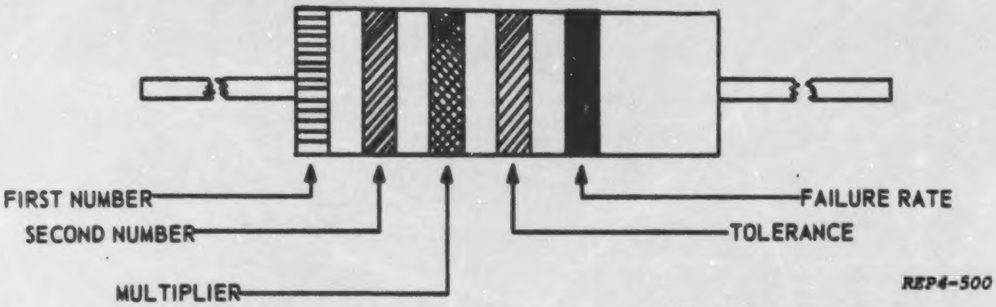


Figure 3-42 REP4-499



A. COLOR CODE MARKING COMPOSITION-TYPE RESISTORS (MIL-STD)

| COLOR | PART | SIGNIFICANT FIGURES OF ELECTRICAL VALUE | | | TOLERANCE | FAILURE RATE PER 1000 HRS |
|---|---|---|---|---|---|---|
| | | 1st Number | 2nd Number | Multiplier | | |
| Black | Capacitor | 0 | 0 | 1 | ±20% | L 5% |
| Brown | --- | 1 | 1 | 10 | ± 1% | M 1% |
| Red | --- | 2 | 2 | 100 | ± 2% | P 0.1% |
| Orange | --- | 3 | 3 | 1000 | --- | R 0.01% |
| Yellow | --- | 4 | 4 | 10000 | --- | S 0.001% |
| Green | Diode | 5 | 5 | 100000 | --- | T 0.0001% |
| Blue | --- | 6 | 6 | 1000000 | --- | |
| Violet | --- | 7 | 7 | 10000000 | --- | |
| Gray | --- | 8 | 8 | | --- | |
| White | --- | 9 | 9 | | --- | |
| Gold | --- | - | - | 0.1 | ± 5% | |
| Silver | Coil | - | - | 0.01 | ±10% | |

B. COLOR CODES FOR PART IDENTIFICATION MARKING

Figure 3-43

3-117. Resistor Color Code

3-118. The published resistance of a resistor is indicated by its markings. Some resistors have the resistance value printed in ohms on the body of the resistor. Others have tags attached to indicate their value. Some resistors are so small that a printed marking is impractical so a color code marking is used. Unfortunabely, resistors are often mounted so that the printed marking cannot be seen or heat discolors the resistor body, making it difficult to read the color code. If you cannot determine the resistance visually, you MUST use a schematic diagram.

3-119. There are two systems used in color coding the resistors. We will cover only the END-TO-CENTER band system. See figure 3-43. In each color code system of marking, three colors indicate the resistance value in ohms. By substituting numbers from the color code chart, the approximate resistance value of a resistor can be determined.

3-120. TOLERANCE. It is difficult and expensive to manufacture a resistor to an exact resistive value. The actual resistive value may be as great as 20 percent from its color code marking and still be a good component. This percent difference between the marked value and the actual value is known as the TOLERANCE of a resistor. A fourth color is used to indicate the tolerance. This band may be omitted if the tolerance is 20 percent.

3-121. FAILURE RATE. It is very important that electronic components be reliable. Lack

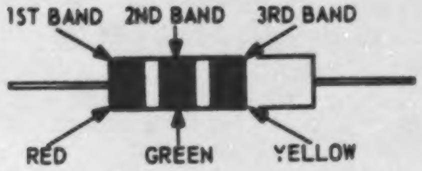


Figure 3-44 REP4-501

of reliability can cause the failure of an important mission. The reliability of resistors is expressed as the percentage of failures per 1000 hours of operation. It is stated as a percentage and indicated by a fifth color band. See figure 3-43. This band is omitted when failure rate is unspecified.

3-122. Figure 3-43 shows the colors used in the color code. Electronic technicians should memorize this color code as soon as possible.

3-123. End-to-Center Band Marking. In this method, the resistor is marked with bands of color at one end of the resistor. The body color has nothing to do with the color code.

3-124. The first color band (nearest the end) will always be the first digit of ohmic value.

3-125. The second color band will always be the second digit of ohmic value.

3-126. The third color band indicates the decimal multiplier or number of zeroes.

3-127. If there is a fourth band, it indicates the tolerance. See figure 3-43. If there is no fourth band, the tolerance is 20%.

3-128. If there is a fifth color band, it indicates the failure rate. See figure 3-43. If there is no fifth band, then the failure rate is unspecified.

3-129. Figure 3-44 shows a carbon resistor with three bands of color. The color bands are read starting from the end and reading toward the center. Refer to figure 3-44 and use the following values:

| BAND | COLOR | NUMERICAL VALUE | SIGNIFICANCE |
|---|---|---|---|
| 1st | Red | 2 | 1st Digit |
| 2nd | Green | 5 | 2nd Digit |
| 3rd | Yellow | 10,000 | Multiplier |

The resistance indicated is 250,000 ohms. There is no 4th band; therefore, the tolerance is 20%.

20% of 250,000 = 50,000

Maximum resistance = 250,000 + 50,000

= 300,000 ohms

Minimum resistance = 250,000 - 50,000

= 200,000 ohms

This resistor could have a resistance between 200,000 and 300,000 ohms and be within tolerance.

3-130. Refer to figure 3-45.

Resistance = 86,000 ohms ± 10%

10% of 86,000 = 8,600

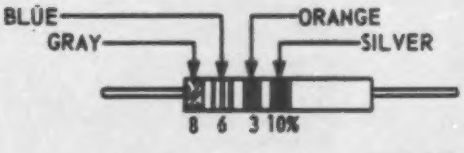
Maximum resistance = 86,000 + 8,600

= 94,600 ohms

Minimum resistance = 86,000 - 8,600

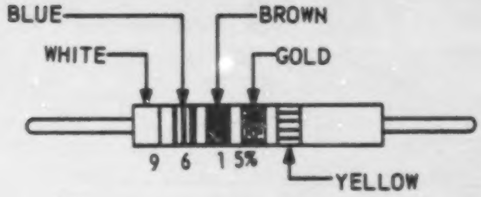
= 77,400 ohms

This resistor could have any resistance value between 77,400 and 94,600 ohms.



REP4-502

Figure 3-45



REP4-503

Figure 3-46

3-131. Refer to figure 3-46.

Resistance = 960 ohms ± 5%

5% of 960 = 48

Maximum resistance = 960 + 48
= 1,008 ohms

Minimum resistance = 960 - 48
= 912 ohms

This resistor could have any resistance value between 912 and 1,008 ohms. The failure rate is 0.001% per 1000 hours of operation.

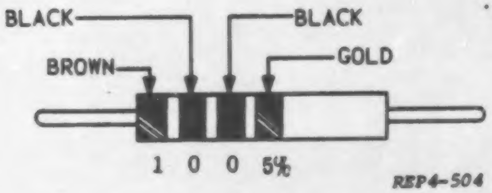
3-132. Figure 3-47 is an example of a resistor with black as the third color band. The color code value of black is zero and indicates that no zeroes are to be added. The multiplier is X1.

Resistance = 10 ohms ± 5%

5% of 10 = 0.5 ohms

Maximum resistance = 10 + 0.5
= 10.5 ohms

Minimum resistance = 10 - 0.5
= 9.5 ohms



REP4-504

Figure 3-47

This resistor could have any resistance value between 9.5 and 10.5 ohms.

3-133. As stated before, the third color band indicates the multiplier. See figure 3-48.

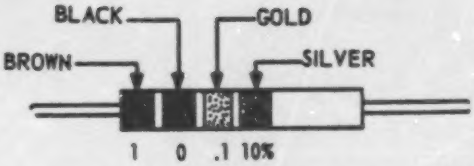


Figure 3-48

REP4-505

3-134. When the third band is GOLD, multiply the first two digits by 0.1. Thus, 0.1 times 10 equals 1 ohm. Resistance equals 1 ohm ±10 percent or any value between .9 and 1.1 ohms.

3-135. See figure 3-49. When the third band is SILVER, multiply the first two digits by 0.01. Thus, 0.01 times 45 equals 0.45 ohms plus or minus 10%.

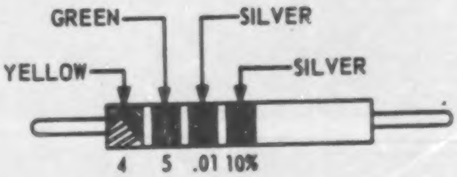
Resistance = 0.45 ohms ± 10%

10% of 0.45 = 0.045 ohms

Maximum resistance = 0.45 + 0.045
= 0.495 ohms

Minimum resistance = 0.45 - 0.045
= 0.405 ohms

This resistor can have any resistance value between .405 and .495.



REP4-506

Figure 3-49

## Chapter 4

## MULTIMETER USES

4-1. When working with electronic circuits, it is sometimes necessary to determine the exact amount of current, voltage, and resistance. These circuit conditions can be determined by the use of a test set known as a multimeter.

4-2. In this chapter you will become familiar with the operation and use of a Multimeter. It functions as an ohmmeter, a voltmeter, and ammeter.

### 4-3. Resistance Measurement

4-4. Figure 4-1 shown a multimeter with two selector switches. The switch on the left is the FUNCTION switch, and the one on the right is the RANGE switch. To measure resistance, place the FUNCTION switch in the OHMS position. The multimeter will now function as an ohmmeter.

4-5. The RANGE switch has seven positions as shown in figure 4-1. Notice that the Greek letter omega ( Ω ), representing ohms, is missing on the first and last positions. These two positions of the RANGE switch are not used for resistance. Begin resistance measurements with the RANGE switch in the ohms times 1 (Ω x1) position, and work up to the most accurate scale.

4-6. The multimeter is equipped with a pair of leads with two corresponding jacks on the lower part of the front panel. To prepare the meter for use, simply insert the red lead into the red jack and the black lead into the black jack.

4-7. Now before proceeding, there is an important safety precaution that must be observed when using the ohmmeter function. NEVER CONNECT AN OHMMETER TO A HOT (OPERATING) CIRCUIT. BE SURE THAT NO POWER IS APPLIED. The internal components of the meter use very little current, and are easily damaged by the application of an external power source.

4-8. Since there is no apparent power applied to the component being tested, a logical question is: Where does the power for deflection on the ohmmeter come from? The multimeter contains its own power supply in the form of a battery located inside the case. The resistive components inside the multimeter are of such values that when the leads are connected together, the meter indicates a full-scale deflection. Because there is no resistance between the connected (shorted) leads, full-scale deflection represents zero resistance.

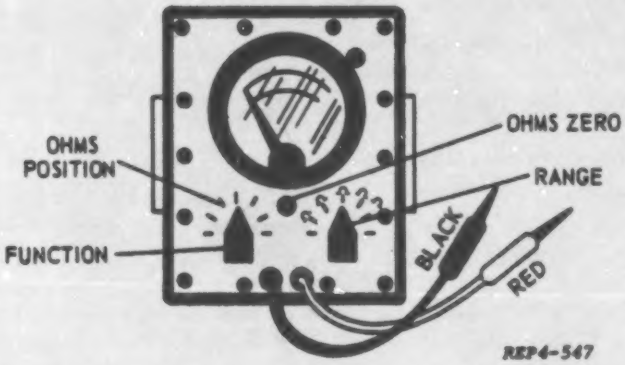


Figure 4-1

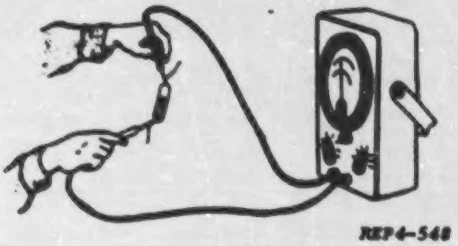


Figure 4-2

4-9. Now before making a measurement, the ohmmeter must be zeroed. This is accomplished by shorting the leads together and adjusting the OHMS ZERO knob, as shown in figure 4-1, so the pointer is directly at the zero mark on the green OHMS scale. A very important factor to remember when making an accurate resistance measurement is to zero the meter each time you select a new range. If the meter is not zeroed each time the range switch is changed, the readings will probably be incorrect.

4-10. When making a resistance measurement, there are certain considerations that must be given to the resistor being tested:

a. The resistor must be isolated. In some instances, a soldered connection will have to be disconnected to isolate the resistor.

b. The meter leads must make good electrical contact with the resistor leads. Points of contact should be checked for dirt, grease, varnish, paint, or any other material that may prevent current flow. If necessary, remove any foreign matter.

c. KEEP YOUR HANDS ON THE INSULATED PORTIONS OF THE LEADS. Your body has a certain amount of resistance that can be measured by the ohmmeter.

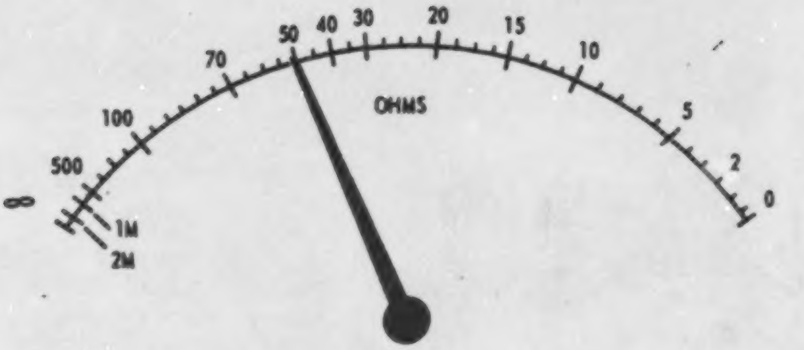
4-11. The proper method of checking a resistor is illustrated in figure 4-2. Connect the red lead to one of the resistor leads and the black lead to the other resistor lead.

4-12. Since zero resistance causes full-scale deflection, you can see that the deflection of the meter is inversely proportional to the resistance being tested. For a small resistor value the deflection will be close to full scale and for a large resistor value the deflection will be considerably less. This indicates that the left portion of the green ohms scale represents high resistance, and the right side of the scale represents low resistance. Zero resistance (an open circuit) is indicated on the extreme left side of the scale. Notice that you read the OHMS scale from RIGHT to LEFT. For example, the pointer in figure 4-3 indicates 51. To determine the value of a resistor, multiply the reading on the meter scale by the RANGE switch setting. If the RANGE switch is on the Ω x 1 position, then the resistor value would be 51Ω.

4-13. As you can see from the ohms scale illustration shown in figure 4-3, the scale marks are crowded on the left side of the scale which makes accurate reading difficult. For this reason, it's best to select a range in which the pointer will fall near mid-scale. Accurate readings are more easily obtained near mid-scale because the divisions are more evenly spaced.

4-14. In order to explain the correlation between the meter reading and the RANGE switch setting, follow this example.

4-15. Suppose you had a 5,000-ohm resistor which you identified as such by using the resistor color code. Now with the RANGE switch in the Ωx1 position, connect the meter across the resistor. The meter pointer will deflect to the extreme left side of the scale (between 2M and ∞ on the scale). Since the Ωx1 range is selected, the reading must be multiplied by 1. In this position, the scale reading is direct. By placing the RANGE switch to the Ωx10 position and zeroing the meter, the pointer now moves to 500 on the scale. Since the Ω x10



TYPICAL OHMMETER SCALE

REP4-549

Figure 4-3

range is now being used, the scale reading must be multiplied by 10. Once again the reading is not in the middle of the scale. The RANGE switch should be moved again.

4-16. With the RANGE switch in the Ωx100 position and the meter zeroed again, the pointer moves to 50 on the scale. Since the Ω x100 range is selected, the reading must be multiplied by 100. The most accurate reading could be made at this point. Of course the reading on this scale must be multiplied by 100.

4-17. If the RANGE switch is positioned to the Ω x1,000 or the Ω x 10,000 ranges measuring accuracy decreases. The most accurate readings are obtained at or near mid-scale.

4-18. Another thing to remember when measuring resistance is the tolerance of the resistor. If the tolerance of the resistor in the preceding example is 10 percent, we could expect a reading between 4500 and 5500 ohms. If a reading is not obtained within these limits, the resistor has probably changed value and should be discarded.

4-19. An open resistor will be indicated by no deflection on the highest ohms range of the meter. A shorted resistor will cause full scale deflection on the lowest ohms range.

4-20. In addition to measuring resistance the ohmmeter is a very useful tool for checking continuity in a circuit. To make a continuity check, first study the circuit diagram, and then check the corresponding parts of the circuit with the ohmmeter. The ohmmeter will indicate high conduction, partial conduction (resistance), or no conduction at all.

4-21. Delete

4-22. When you have finished using the ohmmeter and you are preparing to store it temporarily, be sure to position the FUNCTION switch to any position OTHER than OHMS and remove the leads. Accidental shorting of the leads would completely discharge the batteries and render the ohmmeter useless.

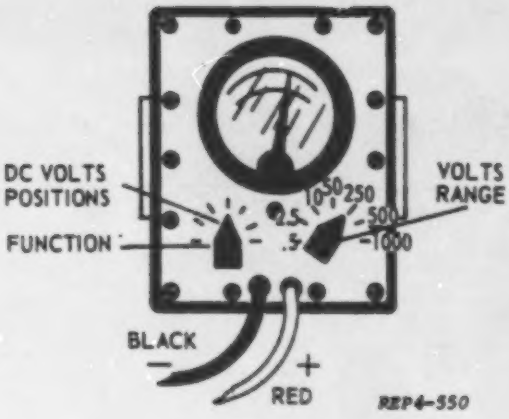


Figure 4-4

4-23. Voltage Measurement

4-24. The multimeter functions as a DC voltmeter if the FUNCTION switch is placed in either of two positions: DC/1 k ohm, or DC/20k ohm. The meter leads must be connected to the meter jacks according to color. This is an especially important point to observe when measuring DC voltages. The red lead will be the positive lead, and the black lead will be negative. See figure 4-4.

4-25. When the meter is connected in a circuit, it becomes a circuit component. Since all meters have some resistance, they will alter the circuit by changing the current slightly. The resistance of the voltmeter depends on the position of the RANGE switch and the FUNCTION switch.

4-26. The DC/20 k ohm position has 20 times as much meter resistance as the DC/1 k ohm position. The higher meter resistance loads the circuit less. This gives a more accurate indication of circuit conditions before the voltmeter was connected. For this reason the highest meter resistance possible should be used.

4-27. Earlier models of voltmeters contained only a 1,000 ohm per volt function and tables of standard voltage values were established with this function. Therefore, many of the tables of standard voltage values you will find in technical orders were made using the 1,000 ohm per volt position. If you wish to compare your readings to standard values taken with a 1,000 ohm per volt voltmeter, you must use the DC/1 k ohm position.

4-28. When using a meter that has a ground lead, always connect this lead to the ground terminal on the equipment before making any tests. If the equipment has no ground terminal, connect the ground lead to the chassis of the equipment. If you do not observe this precaution, you can receive a serious electrical shock.

4-29. With the FUNCTION switch set to either DC/20 k ohm or DC/1 k ohm, consider the RANGE switch and the scale on the meter to be used. When measuring DC voltages, there are seven ranges available: .5, 2.5, 10, 50, 250, 500, and 1000. The setting of the RANGE switch determines the maximum value represented on the meter. When measuring DC voltages, use the black DC scale; to read the scale, see figure 4-5. The three digits, on the bottom of the scale at the extreme right side, indicate the maximum value of the range being used. When the RANGE switch is in the .5 position, the scale represents a maximum of .5 volts (the digit 5 on the second row should

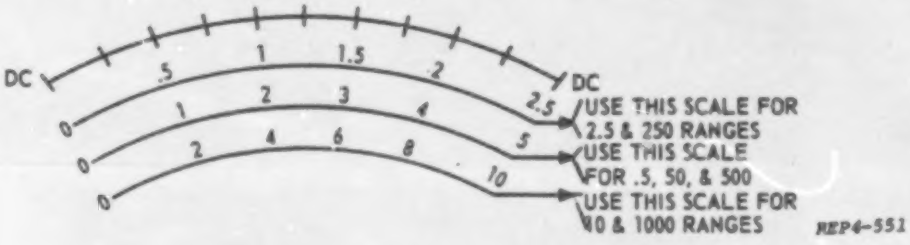

DC
.5
1
1.5
2
DC
2.5
0
1
2
3
4
5
0
2
4
6
8
10
0
USE THIS SCALE FOR 2.5 & 250 RANGES
USE THIS SCALE FOR .5, 50, & 500
USE THIS SCALE FOR 10 & 1000 RANGES
REP4-551

Figure 4-5

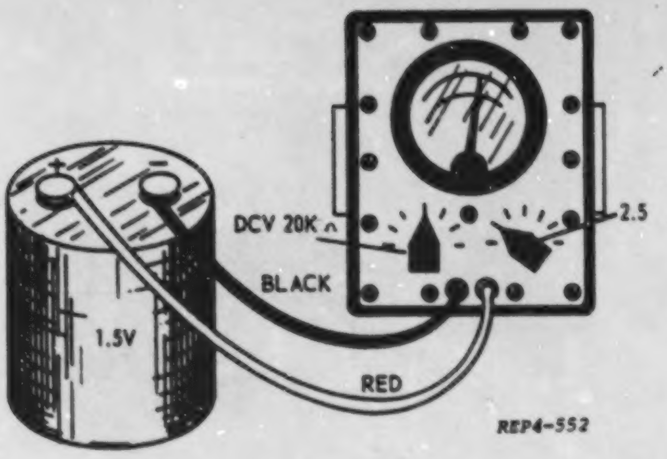


Figure 4-6

be interpreted as .5). To simplify the relationship between the digits below the scale and the setting on the RANGE switch, always use the digits that correspond to the numbers on the RANGE switch. Use 2.5 on the scale for the 2.5 and 250 ranges; the 5 on the scale for .5, 50, and 500 ranges; the 10 on the scale for the 10 and 1000 ranges.

4-30. For explanation purposes, assume that you wish to measure 30 volts DC. In this case, use the 50V range. By placing the RANGE switch to the 50 position, the meter needle should rise to the 3 which represents 30.

4-31. When measuring a known DC voltage, position the RANGE switch to a setting that will cause a near half-scale deflection. The readings taken near the center of the scale are the most accurate. When measuring an unknown DC voltage, always begin on the 1000 range and using the RANGE switch, work down to a safe range. If you do not begin on the highest range, the meter could be burned out. If the meter needle moves to the left reverse the meter leads to the circuit being tested.

4-32. Observe polarity when measuring DC voltages. The negative (black) lead must be connected to the negative point in the circuit, and the positive (red) lead must be connected to the positive point in the circuit. A proper connection is shown in figure 4-6.

4-33. Now observe how a voltage measurement on a component within a circuit is made. Measurement of the voltage drop across a resistor is shown in figure 4-7.

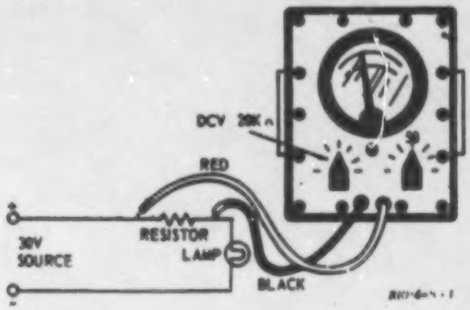


Figure 4-7

360

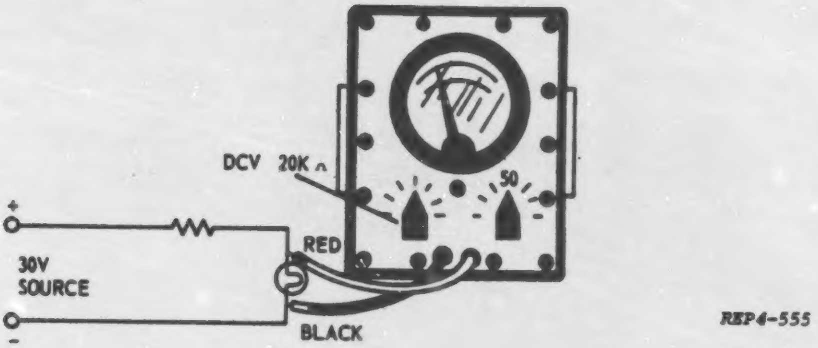


Figure 4-8

4-34. When measuring a DC voltage drop across a component in a circuit, the voltmeter must be connected in parallel with the component. As you can see in the illustration, the red (positive) lead is connected to the positive side of the resistor, and the black (negative) lead is connected to the negative side of the resistor. A voltage reading is obtained on the meter when current flows through the resistor and lamp.

4-35. If you want to know how much voltage is dropped across the lamp, the meter will have to be connected in parallel with the lamp. The proper connection is shown in figure 4-8.

4-36. In figures 4-7 and 4-8, notice that the RANGE switch on the PSM-6 is shown in the 50 position. As stated before, when measuring a known DC voltage, always use the range that will cause mid-scale deflection.

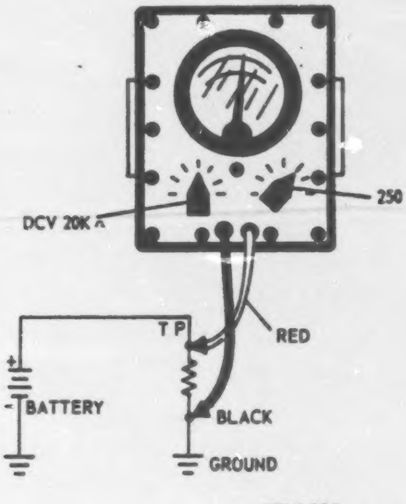


Figure 4-9 REP4-554

3-37. In the event that the meter was inadvertently connected to the circuit backwards, the meter needle would move in the reverse direction. Always check the polarity before connecting the meter.

4-38. Some voltmeter readings will require the use of ground, as a reference point. See figure 4-9. Under these conditions, one voltmeter lead is connected to the equipment ground and the other lead is connected to the test point where voltage is to be measured. Observe polarity.

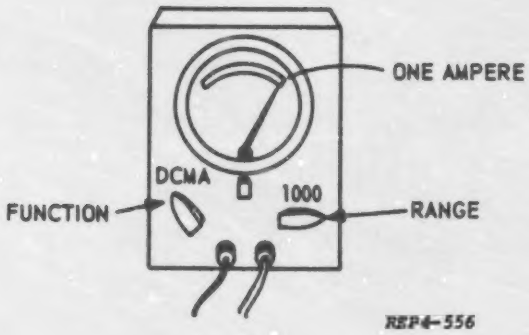
4-39. Current Measurement

4-40. An ammeter measures current, and is often included as an integral part of equipment. Ammeters must be placed in series with the circuit to measure the circuit current. You will be taking current measurements many times in order to understand what is taking place in circuits with unknown voltage or resistance values.

4-41. The multimeter can function as an ammeter to measure current flow, by placing the FUNCTION switch in the DCMA position. With the RANGE switch in the 1000 position, as shown in figure 4-10, DC current measurements from 0 to 1 ampere can be made directly.

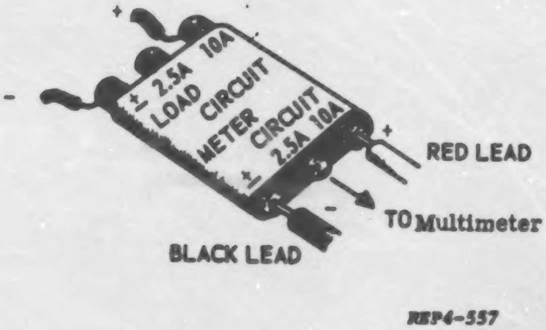
4-42. In order to understand how 1 ampere is indicated with the RANGE switch in the 1000 position, you need to know the meaning of DCMA, and the relationship between amperes and milliamperes.

371



REP4-556

Figure 4-10



REP4-557

Figure 4-11

4-43. The letters DCMA stand for Direct Current MilliAmperes. This means that the direct current is measured in milliamperes instead of amperes; and a meter that measures current values in milliamperes is called a MILLIAMMETER. One thousand milliamperes equals one ampere.

4-44. The range of the ammeter can be extended with the addition of an accessory called a SHUNT. Using a shunt such as the one shown in figure 4-11, DC currents up to 10 amperes can be measured.

4-45. In reality, with the shunt the multimeter is an ammeter (up to 10 amperes). WITHOUT the shunt, the multimeter is a milliammeter (up to 1000 milliamperes).

4-46. When the multimeter is being used to measure current, the black DC scale is used. It is the same scale used when measuring DC voltages. Refer to figure 4-5. As stated before, with the RANGE switch on 1000 and the FUNCTION switch on DCMA, the black DC scale represents a maximum of 1000 milliamperes, or 1 ampere. The 10 on the bottom row of digits (extreme right side) represents 1000 milliamperes or 1 ampere. The 8 on the bottom row represents 800 milliamperes, or 0.8 amperes. The 6 on the bottom row represents 600 milliamperes, or 0.6 amperes, and so on.

4-47. When the RANGE switch is placed to the 500 position, the second row of digits below the black DC scale is used. In this case, the maximum value represented by the DC scale is 500 milliamperes or 0.5 amperes. The 5 on the second row represents 500 milliamperes or 0.5 amperes. The 4 on the second row represents 400 milliamperes or 0.4 amperes.

4-48. By placing the RANGE switch to the 250 position, the top row of digits is used. The maximum value represented by the DC scale is now 250 milliamperes, or 0.25 amperes. The setting of the RANGE switch determines the maximum value represented by the DC scale. Always use the row of digits that corresponds to the RANGE switch setting.

4-49. Never attempt to measure currents greater than the setting of the RANGE switch. To measure a current of unknown value, always start with the highest range possible and then work down. Use the range that gives near half-scale deflection. If this procedure isn't followed, the meter could be burned out. Increase the range with an external shunt, if necessary, but do not exceed the marked current.

4-50. The test leads should be connected to the multimeter with the red lead to the red jack and the black lead to the black jack.

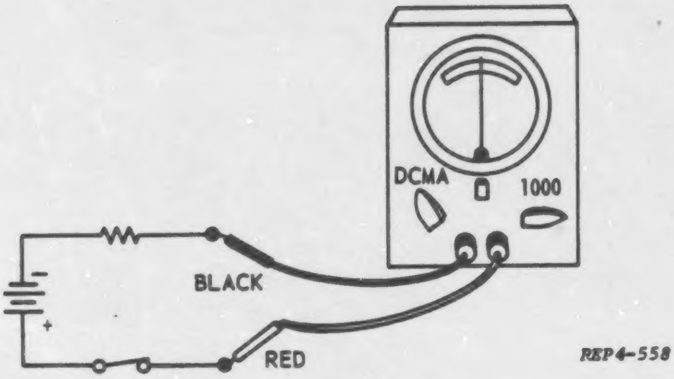


Figure 4-12

4-51. Now that the meter is set up to measure current and the leads are properly connected, observe how it is to be connected into the circuit to be tested. DC ammeters must be connected in series with the component through which the current is flowing. You must use the correct polarity. That is, the red (positive) lead must be connected to the positive point in the circuit and the black (negative) lead must be connected to the negative point in the circuit. The proper method of connection is shown in figure 4-12.

4-52. As stated before, with a shunt currents up to 10 amperes can be measured. Connect the negative point in the circuit to the ± terminal on the LOAD CIRCUIT end (figure 4-13), and connect the positive circuit point to either the 10 A or 2.5 A terminal. You can decide which terminal to use from the amount of current you intend to measure.

4-53. Now to properly connect the multimeter connect the black lead to the ± jack on the METER CIRCUIT end of the shunt and connect the red lead to either 10 A or 2.5 A jack. The meter circuit must connect to the same current value used for the load circuit.

4-54. To measure currents between 0 and 2.5 amperes, set the RANGE switch on 2.5. For currents between 2.5 and 10 amperes, set the RANGE switch on 10. An important fact to remember when using the shunt, is that the readings on the meter are in AMPERES rather than milliamperes.

4-55. The multimeter can be used to measure current in microamperes. As

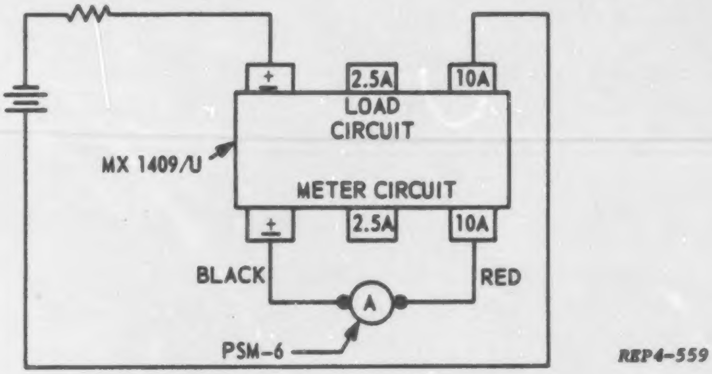


Figure 4-13

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you know, the microampere is also a subdivision of the ampere; one millionth of an ampere. It takes 1,000,000 microamperes to make 1 ampere.

4-56. By placing the FUNCTION switch to the 100μA SPECIAL position, the multimeter acts as a 0 to 100 microampere DC microammeter.

4-57. When you need to measure currents too small for the ammeter or milliammeter range, use the 100μA SPECIAL position. So far it has been explained how the RANGE switch changes the range of the meter. However, when using the 100μA SPECIAL function, the RANGE switch can be on any position, for it will not change the range.

4-58. AC Voltage Measurements

4-59. To measure alternating current voltage, the FUNCTION switch must be set to the AC VOLTS position. The same procedures used to measure DC voltage apply, except the reading is taken from the Blue AC volts scale and the polarity of the test leads is not important.

## Chapter 5

## DC RESISTIVE CIRCUITS

5-1. The most basic circuit in electronics is the series circuit. No matter how complex a circuit may appear, it can be electrically reduced to a simple series circuit. In order to understand what a series circuit is, look at figure 5-1.

5-2. This is a circuit because there is a complete path for current flow. It is a series circuit because there is only one possible path for current to flow. The current flows from the negative side of the battery, through the conductor, through the resistor, through another conductor and back to the positive side of the battery. The electrical devices in a series circuit are connected end-to-end. The circuit shown contains the three basic requirements for any circuit:

a. A source of power (battery).

b. A load device (resistor).

c. A conductor (wire).

Most practical circuits also contain two other items:

d. A safety device (fuse).

e. A control device (switch).

With all five components in the circuit, they would appear as shown in figure 5-2.

5-3. Figure 5-2 is a DC series circuit. Current will flow in only one direction, from the negative side of the battery, through the switch, fuse and conductor, through the resistor, and back to the positive side of the battery. Remember, current flows from the negative terminal of the battery through the external circuit and back to the positive terminal of the battery.

5-4. Close the switch in figure 5-3, and current will flow. The three ammeters would show how much current is flowing at various points in the circuit. All the ammeters will read the same amount of current. This is the first important thing to remember about a series circuit - current is the same at all points throughout the circuit.

5-5. This is sometimes expressed in formula form as:

| $I_t$ | = | $I_{R1}$ | = | $I_{R2}$ |
|---|---|---|---|---|
| Total Current | | Current Thru R1 | | Current Thru R2 |

It doesn't matter how many resistors you have. If there were five resistors connected in series in the circuit, the formula would be:

$$I_t = I_{R1} = I_{R2} = I_{R3} = I_{R4} = I_{R5}$$

5-6. Total resistance ($R_t$) in a series equals the sum of the individual resistances. Stated as a formula:

$$R_t = R_1 + R_2 + \ldots$$

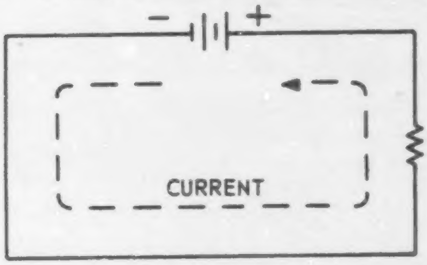

Figure 5-1

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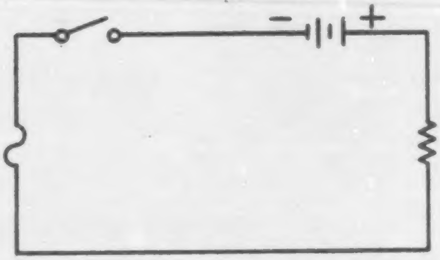

Figure 5-2

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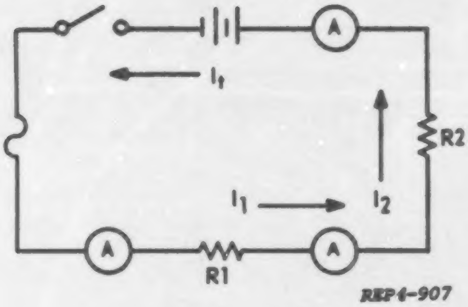

Figure 5-3

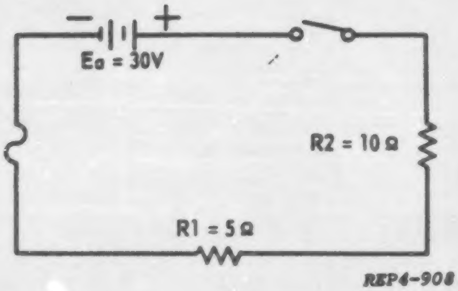

Figure 5-4

5-7. Before looking at what makes a series circuit work, review the meaning of the following terms:

a. Voltage - A force which causes current to flow.

b. Current - Electrons moving in a given direction.

c. Resistance - An opposition to current flow.

The relationship of these terms can be shown by the use of Ohm's Law.

5-8. Ohm's Law states that the current in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance.

5-9. Ohm's Law is normally expressed as a formula:

$$I = \frac{E}{R}$$

By substituting numbers for E and R it can be shown that as E is made larger, I becomes larger; and as R is made larger, I becomes smaller.

5-10. Ohm's Law is expressed in two other forms:

$$E = IR$$

$$R = \frac{E}{I}$$

If any two of the quantities are known the other can be found.

5-11. To illustrate the use of Ohm's Law, find the current in figure 5-4. It is a series DC circuit with a power source, a control device, a safety device, conductors, and a load (consisting of two resistors). In order to find the total current first find the total resistance. Total resistance ($R_t$) in a series circuit equals the sum of the individual resistances. Stated as a formula:

$$R_t = R1 + R2 + \ldots$$

Substituting the values of R1 and R2

$$R_t = 5 \text{ ohms} + 10 \text{ ohms} = 15 \text{ ohms}$$

5-12. If the circuit had contained five, 10, or 100 resistors in series, they would all have to be added to find the total resistance. The battery or applied voltage ($E_a$) is 30 V; $R_t = 15\,\Omega$. Then:

$$I_t = \frac{E_a}{R_t} = \frac{30V}{15\Omega} = 2A$$

The 2 amperes of current will be flowing everywhere in the circuit.

5-13. Now notice what effect a change in resistance or voltage will have on current flow. For example, when the applied voltage remains constant and the resistance is doubled, current will be reduced to one half of its original value. In the figure 5-4, for instance, the resistance of the circuit would now be 30 ohms and with the voltage remaining constant:

$$I_t = \frac{E_a}{R_t} = \frac{30V}{30\Omega} = 1A$$

5-14. On the other hand, if voltage remains constant, and the resistance is reduced to one-half of its original value, current will double its original value.

$$I_t = \frac{E_a}{R_t} = \frac{30V}{7.5\Omega} = 4A$$

5-15. To summarize the relationships of voltage, current and resistance:

a. If resistance remains constant and voltage increases, current will increase.

b. If resistance remains constant and voltage decreases, current will decrease.

c. If voltage remains constant and resistance increases, current will decrease.

d. If voltage remains constant and resistance decreases, current will increase.

5-16. Voltage is the force which causes current to flow. It is not the same everywhere in a series circuit, but is divided among the individual resistances according to their size - The voltage developed by each resistance is called a "voltage drop" and the total of the voltage drops is always equal to the applied voltage - This fact is expressed in the formula:

| $E_a$ | = | $E_{R1}$ | + | $E_{R2}$ | + . . . |
|---|---|---|---|---|---|
| Applied Voltage | | Voltage drop of R1 | | Voltage drop of R2 | |

5-17. In figure 5-4 the applied voltage, $E_a$, is 30 Volts. These 30 volts are "dropped" across R1 and R2. The resistors are not the same size so the voltage drops will not be equal. By using Ohm's Law, the voltage drop across each resistor can be found.

5-18. Listing the known facts about figure 5-4:

$E_a = 30$ volts

$I_t = I_{R1} = I_{R2} = 2$ amperes.

R1 = 5 ohms

R2 = 10 ohms

Ohms Law formula; $E = IR$ or in this case $E_{R1} = I_{R1} \times R1$. Substituting: $E_{R1} = 2A \times 5\,\Omega = 10V$. So the voltage drop across R1 = 10V.

$$E_{R2} = I_{R2} \times R2$$

$$E_{R2} = 2A \times 10\Omega = 20V$$

5-19. The fact that the individual voltage drops add to equal the applied voltage can be confirmed by the formula:

$$E_a = E_{R1} + E_{R2}$$

$$30V = 10V + 20V$$

$$30V = 30V$$

5-20. In any DC series circuit, such as the one just discussed, the missing quantity (voltage, resistance, or current), can be calculated by using Ohm's Law, if any two of the quantities are known.

5-21. Another important thing to remember is, when there are two or more resistors in a circuit, the larger resistance will have the larger voltage drop.

R1 = 5 ohms

R2 = 10 ohms

$E_{R1} = 10$ V

$E_{R2} = 20$ V

5-22. In the circuit shown in figure 5-5, solve for the total resistance, total current, and individual voltage drops. The applied voltage and the size of the resistors are known.

$R_t$ = R1 + R2 + R3

= 30 ohms + 60 ohms + 10 ohms

= 100 ohms

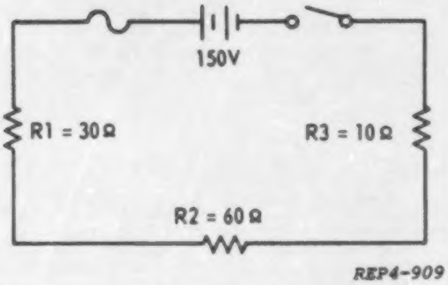

Figure 5-5

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{150\,V}{100\,\Omega}$$

$$= 1.5\ A$$

$$E_{R1} = I_t \times R1$$

$$= 1.5 \text{ amps} \times 30 \text{ ohms}$$

$$= 45 \text{ volts}$$

$$E_{R2} = I_t \times R2$$

$$= 1.5 \text{ amps} \times 60 \text{ ohms}$$

$$= 90 \text{ volts}$$

$$E_{R3} = I_t \times R3$$

$$= 1.5 \text{ amps} \times 10 \text{ ohms}$$

$$= 15 \text{ volts}$$

Check in the formula:

$$E_a = E_{R1} + E_{R2} + E_{R3}$$

$$150\,V = 45\,V + 90\,V + 15\,V$$

$$150\,V = 150\,V$$

5-23. Before making false starts, always examine the circuit to see what is known. Remember, anytime we have two knowns we can always solve for the unknown. In the circuit shown in figure 5-6, find the size of R1.

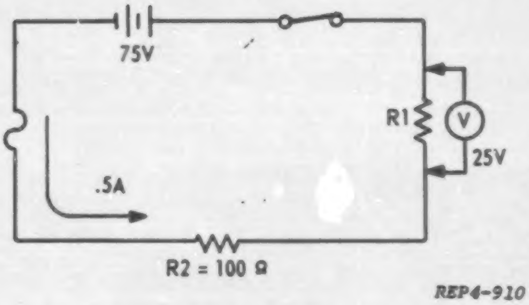

Figure 5-6

What is known about R1?

a. In a series circuit the current is the same throughout the circuit. Thus, if 0.5 amps of current is flowing through R2, then the same amount of current must be flowing through R1.

b. This 0.5 amps of current flowing through R1 produces a voltage drop of 25 volts which is indicated by the voltmeter in the circuit diagram.

These two facts allow the use of Ohm's Law:

$$R = \frac{E}{I}$$

$$R1 = \frac{E_{R1}}{I_t} = \frac{25\,V}{0.5\,A} = 50\,\Omega$$

5-24. Take what you know and use it to calculate what you don't know.

5-25. Up to this point in the analysis of series circuits, you have been working with Ohm's Law. Now you will learn to work with Kirchhoff's Laws for current and voltage. These laws may be stated as follows:

a. The algebraic sum of the currents at any junction of conductors is zero. This means that the sum of all currents flowing to a point must be equal to the sum of all currents flowing away from that point.

b. The algebraic sum of the applied voltage and the voltage drops around any closed circuit is zero. This means that in any closed circuit, the applied voltage is equal to the sum of the voltage drops around the circuit.

Stated in formula form:

a. $I_t = I_{R1} + I_{R2} + \dots$

b. $E_a = E_{R1} + E_{R2} + \dots$

5-26. Kirchhoff's Laws are used to find unknown quantities of current and voltage in any part of a series circuit. You found that the total current flows through each resistor in a series circuit, regardless of size or number of resistors. So, current is the same throughout the circuit. This is a direct application of Kirchhoff's current law. Refer to figure 5-7. If 2 amperes of current flow into point A, 2 amperes of current must flow away from point A.

5-27. Using the circuit in figure 5-8, apply Ohm's and Kirchhoff's Laws to solve for total current. First find the current through resistor R1 by applying Ohm's Law. Substitute the known values of $E_{R1}$ and R1 and solve for $I_{R1}$.

Since $I = \frac{E}{R}$

$$I_{R1} = \frac{E_{R1}}{R1} = \frac{5\text{ V}}{5\Omega} = 1 \text{ amp}$$

5-28. The current flow through resistor R1 is 1 ampere. By applying Kirchhoff's current law, you should be able to determine the total current. The total current is 1 ampere because in a series circuit, the current at any point in the circuit is equal to the total current.

5-29. To prove this point, add all the resistors and apply Ohm's Law to check the above:

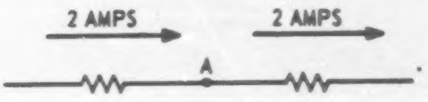

Figure 5-7

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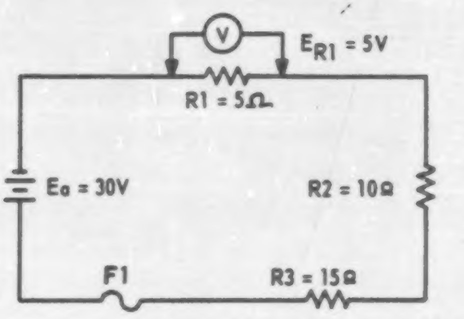

REP4-912

Figure 5-8

$$I_t = \frac{E_a}{R_t} = \frac{30\text{ V}}{30\Omega} = 1\text{ A}$$

5-30. Once the current at any point in a series circuit is known, Kirchhoff's current law may be used for finding total current. For example, the illustration shown in figure 5-9 has three unknown resistors connected across a 165-volt battery, and the current through resistor R1 is 15 amps. By applying Kirchhoff's current law the total current is 15 amps. Ohm's Law is used to solve for total resistance.

$$R_t = \frac{E_a}{I_t} = \frac{165\text{ V}}{15\text{ A}} = 11\Omega$$

5-31. Once you have the basic ideas, all of these problems are pretty much alike. Now, take up Kirchhoff's voltage law. This law deals with voltage distribution in a closed circuit.

5-32. Kirchhoff's voltage law states that the applied voltage is equal to the sum of the individual voltage drops in a closed circuit. Referring to the circuit shown in figure 5-10, investigate this law.

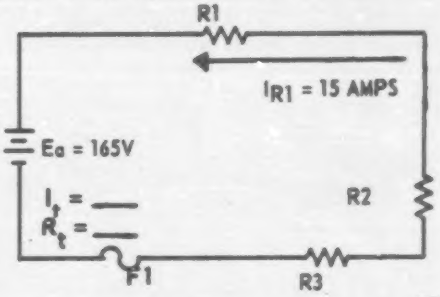

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Figure 5-9

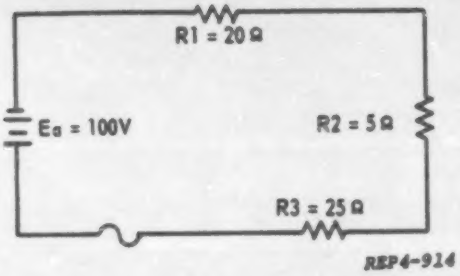

Figure 5-10

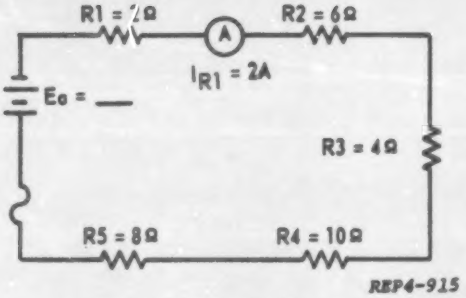

Figure 5-11

5-33. The applied voltage is known and the value of each resistor is known. By using the total resistance equation, $R_t = R1 + R2 + R3$, the total resistance can be determined. By substituting the values in the equation:

$$R_t = 20 \text{ ohms} + 5 \text{ ohms} + 25 \text{ ohms}$$

The total resistance is 50 ohms. By using Ohm's Law, the total current is:

$$I_t = \frac{E_a}{R_t} = \frac{100\,V}{50\,\Omega} = 2\ A$$

5-34. In order to determine the voltage drop across each resistor, simply use a form of Ohm's Law, E = IR.

$$\begin{aligned} E_{R1} &= I_t R1 \\ &= 2\ A \times 20 \text{ ohms} \\ &= 40\ V \end{aligned}$$

$$\begin{aligned} E_{R2} &= I_t R2 \\ &= 2\ A \times 5 \text{ ohms} \\ &= 10\ V \end{aligned}$$

$$\begin{aligned} E_{R3} &= I_t R3 \\ &= 2\ A \times 25 \text{ ohms} \\ &= 50\ V \end{aligned}$$

5-35. Kirchhoff's Law states that the sum of the voltage drops is equal to the applied voltage. Check this statement using the total voltage equation.

$$\begin{aligned} E_a &= E_{R1} + E_{R2} + E_{R3} \\ &= 40\ V + 10\ V + 50\ V \\ &= 100\ V \end{aligned}$$

5-36. Since the applied voltage is 100 volts, and the application of Kirchhoff's voltage law, produces 100 volts; it checks out.

5-37. Solve another problem. This time the applied voltage is the unknown quantity. Use both Kirchhoff's and Ohm's Laws to check the solution. Use the circuit shown in figure 5-11.

5-38. Since the current through resistor R1 is known, the total current of the circuit is known (Kirchhoff's current law). By using the total resistance equation, the total resistance can be determined. Calculate the applied voltage using Ohm's Law (E = IR). Solve for the applied voltage using Kirchhoff's Law by taking the sum of the voltage drops in the loop and see if the answers are the same.

Solving with Ohm's Law E = IR, first determine total resistance.

$$\begin{aligned} R_t &= R1 + R2 + R3 + R4 + R5 \\ &= 2\Omega + 6\Omega + 4\Omega + 10\Omega + 8\Omega \\ &= 30\Omega \end{aligned}$$

Then:

$$\begin{aligned} E_a &= I_t R_t \\ &= 2\ A \times 30 \text{ ohms} \\ &= 60 \text{ volts} \end{aligned}$$

In this case, before applying Kirchhoff's Law, you must first use Ohm's Law to find the individual voltage drops.

Voltage drop across R1:

$$E_{R1} = I_tR1$$

$$= 2\text{ A} \times 2\text{ ohms}$$

$$= 4\text{ V}$$

Voltage drop across R2:

$$E_{R2} = I_tR2$$

$$= 2\text{ A} \times 6\text{ ohms}$$

$$= 12\text{ V}$$

Voltage drop across R3:

$$E_{R3} = I_tR3$$

$$= 2\text{ A} \times 4\text{ ohms}$$

$$= 8\text{ V}$$

Voltage drop across R4:

$$E_{R4} = I_tR4$$

$$= 2\text{ A} \times 10\text{ ohms}$$

$$= 20\text{ V}$$

Voltage drop across R5:

$$ER_5 = I_tR5$$

$$= 2\text{ A} \times 8\text{ ohms}$$

$$= 16\text{ V}$$

Applying Kirchhoff's Law

$$E_a = E_{R1} + E_{R2} + E_{R3} + E_{R4} + E_{R5}$$

$$= 4\text{ V} + 12\text{ V} + 8\text{ V} + 20\text{ V} + 16\text{ V}$$

$$= 60\text{ volts}$$

5-39. Looking back at the answer derived using Ohm's Law, you will see that the answer is the same in both methods.

5-40. Electrical Power and Energy

5-41. Power is the rate of doing work per unit of time. Work results from a force acting on a mass over a distance. The operation of electrical circuits involves a force (voltage) acting on a mass (electrons) over a distance. The amount of time required to perform a given amount of work will determine the power expended or dissipated. Expressed as an equation, the relationship between power, work, and time is:

$$P = \frac{\text{Work}}{t}$$

Where: P = power in watts

Work = work in joules

t = time in seconds

5-42. Since energy is the capacity to do work, power can be defined as the time rate of developing or expending energy. In electrical circuits, electrical energy is transformed into heat energy. Following the law of conservation of energy, the heat energy will be equal in value to the electrical energy causing it. Therefore, by measuring the amount of heat energy given off by an electrical circuit in a given amount of time, the amount of electrical power consumed in the circuit can be determined.

5-43. An experiment measuring the heat given off by an electrical circuit was performed by an English physicist, James Joule in 1843. He experimentally proved that the amount of heat produced by an electrical circuit was dependent upon current and resistance. This proportional relationship is known as Joule's Law, and is stated as follows:

> The amount of heat produced by a circuit element is directly proportional to resistance, the square of the current, and time.

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Expressed as an equation:

$$\text{Heat} = R \times I^2 \times t$$

5-44. The amount of heat energy produced is equal to the amount of work performed.

Therefore: $\text{Work} = R \times I^2 \times t$

Since: $P = \frac{\text{WORK}}{t}$

$$P = \frac{R \times I^2 \times t}{t}$$

$$P = I^2R$$

5-45. By substituting Ohm's Law values into the power formula developed from Joule's Law, other equations can be derived that are useful in determining power.

$$P = I^2R$$

Since: $I = \frac{E}{R}$

$$P = I^2R$$

$$= \left(\frac{E}{R}\right)^2 \times R$$

$$= \frac{E^2}{R^2} \times R$$

$$= \frac{E^2}{R}$$

The resultant equation is useful when the resistance and voltage are known.

5-46. The power formula can also be expressed as an equation in terms of current and voltage.

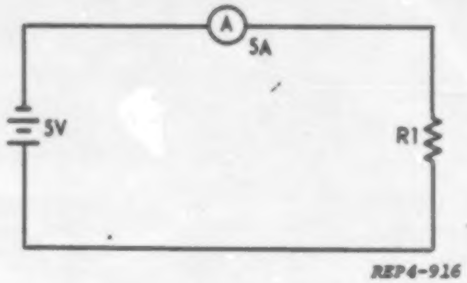

Figure 5-12

Since: $R = \frac{E}{I}$

$$P = I^2R$$

$$= I^2\left(\frac{E}{I}\right)$$

$$= I^2 \times \frac{E}{I}$$

$$= IE$$

5-47. The unit of measure for electrical power is the WATT(W). In each of the three derived equations, power will be in watts. As an example: When 1 volt of potential difference produces a current of 1 ampere, the power expended is 1 watt. The watt represents the rate at any given instant at which work is being done in moving electrons through a circuit.

Example: What is the power expended in a circuit when an EMF of 5 volts causes a current of 5 amps as indicated in figure 5-12?

Given: I = 5 amps

E = 5 volt

P = ?

Solution: P = IE

= 5 amps x 5 volts

= 25 watts

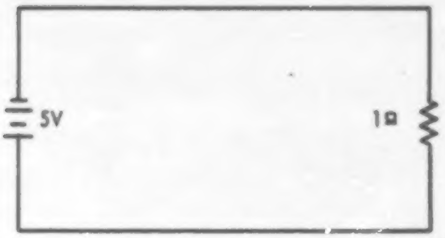

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Figure 5-13

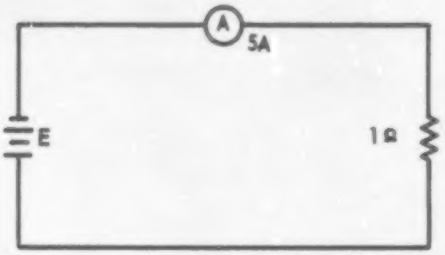

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Figure 5-14

5-48. If voltage and resistance are known, as in figure 5-13, the formula containing voltage and resistance is best suited to compute power:

Given: $E = 5$ volts

$R = 1$ ohm

$P = ?$

Solution: $P = \frac{E^2}{R}$

$= \frac{25}{1}$

$= 25$ watts

5-49. Had the current and resistance been known as in figure 5-14, the formula $P = I^2R$ would apply.

Given: $I = 5$ amps

$R = 1$ ohm

$P = ?$

Solution: $P = I^2R$

$= (5)^2(1)$

$= 25$ watts

5-50. The previous examples demonstrated that any form of the power formula may be used to find power in a circuit. Likewise if the power dissipated in a simple circuit is known and the value of any one of the other circuit quantities is known (E, I, or R), the value of the remaining quantities can be found.

Example: The power dissipated by the 1 ohm resistor in figure 5-15 is 25 watts. What is the value of current and voltage in the circuit?

Given: $P = 25$ watts

$R = 1$ ohm

$E = ?$

Solve for E: $P = \frac{E^2}{R}$

$E^2 = PR$

$E = \sqrt{PR}$

$= \sqrt{25 \times 1}$

$= \sqrt{25}$ or 5 volts

Solve for I: $P = I^2R$

$\frac{P}{R} = \frac{I^2R}{R}$

$\frac{P}{R} = I^2$

$I^2 = \frac{P}{R}$

$I = \sqrt{\frac{P}{R}}$

$I = \sqrt{\frac{25}{1}}$

$= \sqrt{25}$

$= 5$ amps

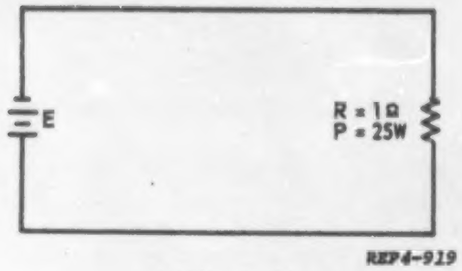


Figure 5-15

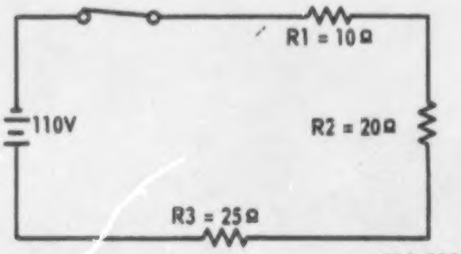


Figure 5-16

5-51. With a knowledge of transposition of equations, the solution of a simple circuit can be found when any two values are known. Circuits having known values of power and current, or power and resistance, can be solved similarly to the circuit of figure 5-15 by using Joule's Law and Ohm's Law correctly. Always begin circuit analysis by determining what is given and choosing a formula with two known values and an unknown that you wish to find.

5-52. So far the unit of electrical power with respect to the watt has been discussed. Quite frequently a larger unit of electrical power called a KILOWATT (kW) is used. One kW equals 1000 watts. Since power is the rate of doing work or consuming energy, the length of time power is used is the true measure of energy consumed. It is common practice to purchase electrical energy by WATT-HOURS (watts x hours). This unit is so small that the unit KILOWATT-HOURS, equal to 1000 watt hours, is used. As an example, a 100-watt bulb requires 100 watts of power for proper operation and comsumes 100-watt hours of energy in 1 hour. In terms of kilowatt-hours, the lamp uses 0.1 hour in 1 hour. In 10 hours of operation, the bulb would consume 1 kilowatt-hour of energy. In 24 hours, the bulb would consume 2.4 kilowatt-hours. At 5 cents per kilowatt hour this would cost 12 cents.

Example: Three resistors are connected in series across a 110V source as shown in figure 5-16. With the information given, find $R_t$, $I_t$, $E_{R1}$, $E_{R2}$, $E_{R3}$, $P_{R1}$, $P_{R2}$, $P_{R3}$, $P_t$, and the kilowatt-hours consumed in 12 hours.

Solutions: $R_t = R1 + R2 + R3$

$= 10 + 20 + 25$

$= 55$ ohms

$I_t = \frac{E_a}{R_t}$

$= \frac{110\,V}{55\,\Omega}$

$= 2$ amps

$E_{R1} = I_{R1}R_1$

$= 2\,A \times 10$ ohms

$= 20\,V$

$E_{R2} = I_{R2}R2$

$= 2A \times 20$ ohms

$= 40\,V$

$E_{R3} = I_{R3}R3$

$= 2\,A \times 25$ ohms

$= 50\,V$

$P_{R1} = I^2R$

$= 2^2 \times 10$ ohms

$= 40\,W$

$P_{R2} = I^2R$

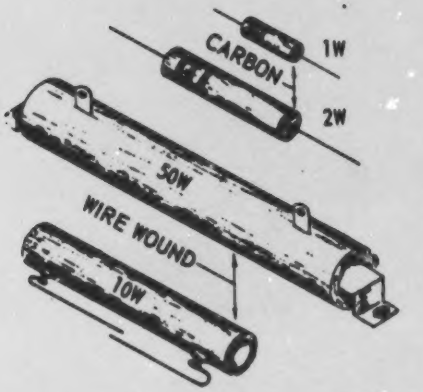
$= 2^2 \times 20$ ohms

$= 80\,W$

$P_{R3} = I^2R$

$= 2^2 \times 25$ ohms

$= 100\,W$



REP4-921

Figure 5-17

5-53. Now that it is known how much power is being expended by each resistor, simply take the sum of the individual powers for the total power. Stated in formula form:

$$P_t = P_{R1} + P_{R2} + P_{R3}$$

$$= 40\,W + 80\,W + 100\,W$$

$$= 220\,W$$

5-54. Another way to determine the total power expended in a circuit is to multiply the total current by the applied voltage. Stated in formula form:

$$P_t = I_t \times E_a$$

$$= 2\,A \times 110\,V$$

$$= 220\,W$$

5-55. To determine the number of kilowatt-hours, the following formula can be used:

$$kWh = \frac{W \times t \text{ (time in hours)}}{1000}$$

$$= \frac{220 \times 12}{1000}$$

$$= \frac{2640}{1000}$$

$$= 2.64$$

5-56. Electrical components are often given a power rating. The power rating in watts indicates the rate at which the device can convert electrical energy into another form of energy such as light, heat, or motion. An example of such a rating is noted when comparing a 150-watt lamp with a 100-watt lamp. The higher wattage rating of the 150-watt lamp indicates it is capable of converting more electrical energy into light energy than the lamp of the lower rating. Other examples of devices rated in this manner are soldering irons and toasters.

5-57. In some electrical devices the wattage rating indicates the maximum power the device is designed to dissipate, rather than the normal operating power. A 150-watt lamp, for example, dissipates 150 watts when operated at the rated voltage printed on the bulb. In contrast, a device such as a resistor is not normally given a voltage or a current rating. A resistor is given a power rating in watts and can be operated at any combination of voltage and current as long as the power rating is not exceeded. In most circuits the actual power dissipated by a resistor will be considerably less than the resistor's power rating. In well-designed circuits a safety factor of 100% or more is allowed between the actual dissipation of the resistor in the circuit and the power rating listed by the manufacturer. The wattage rating of the resistor is thus the maximum power the resistor can dissipate without damage from overheating.

5-58. Resistors of the same resistance value are available with different wattage ratings. Carbon resistors, for example, are commonly made in wattage ratings of 1/8, 1/4, 1/2, 1, and 2 watts. The larger the physical size of a carbon resistor, the higher its wattage rating, since a larger amount of material will radiate more heat.

5-59. When resistors of wattage ratings greater than 2 watts are needed, wire-wound resistors are normally used. Wire-wound resistors are made in sizes between 5 and 200 watts with special types being used for power in excess of 200 watts. See figure 5-17.

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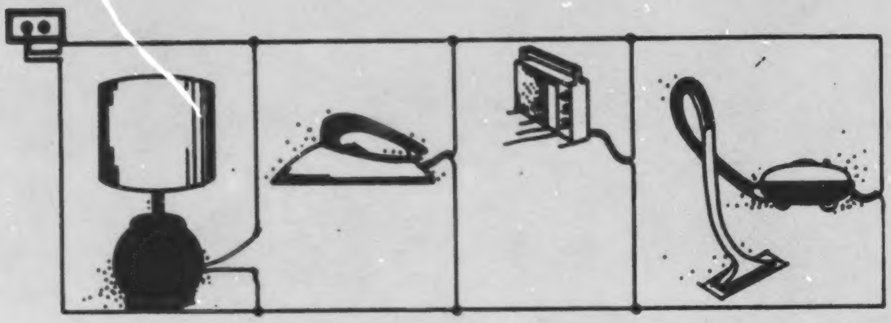


REP4-922

Figure 5-18

5-60. Characteristics of Series DC Circuits

a. The same current flows through each part of a series circuit.

b. The total resistance of a series circuit is equal to the sum of the individual resistances.

c. The applied voltage in a series circuit is equal to the sum of the individual voltage drops.

d. The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.

e. The total power dissipated in a series circuit is equal to the sum of the individual power dissipations.

5-61. Parallel Resistive Circuits

5-62. It is often necessary to connect electrical devices so the entire source of voltage is across each device. A circuit having more than one path for current flow is a parallel circuit. The diagram in figure 5-18 shows a parallel circuit that you should be very familiar with in your home.

5-63. The same voltage source is being applied across the lamp, iron, radio, and vacuum cleaner. This brings you to the requirements for a parallel circuit. They are as follows:

a. A power source

b. Conductors

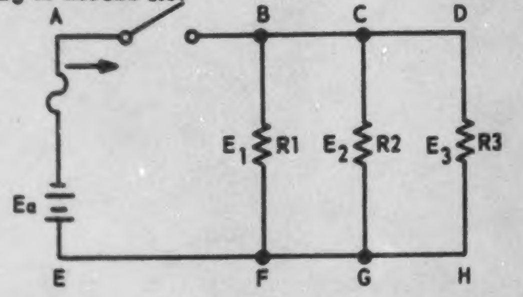
c. Load devices

d. More than one path for current flow.

5-64. Refer to circuit in figure 5-19. Note that points A, B, C, and D are connected together and are one point electrically when the switch is closed. Similarly points E, F, G, and H comprise another electrical point. The applied voltage appears between points B and F, between points C and G, as well as between points D and H. When resistors are connected in parallel across a voltage source, each resistor has the same voltage applied. The currents may differ, depending on the values of resistance. The voltage in a parallel circuit may be expressed mathematically as follows:

$$E_a = E_1 = E_2 = E_3$$

Where $E_a$ is the applied voltage, $E_1$ is the voltage across R1, $E_2$ is across R2, and $E_3$ is across R3.



REP4-923

Figure 5-19

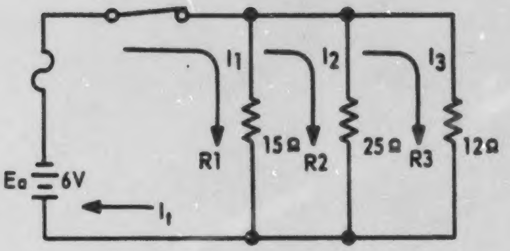


Figure 5-20 REP4-924

5-65. Refer to the circuit in figure 5-20. Note that the total current divides among the branches in a parallel circuit in a manner depending on the resistance of each branch. Branches in a parallel circuit with low resistance draw more current than branches with high resistance. Kirchhoff's current law, as you remember, states: The current flowing toward a point is equal to the current flow away from a point. Therefore, the current flow in the circuit may be expressed mathematically as follows:

$$I_t = I_1 + I_2 + I_3$$

5-66. Where $I_t$ is the total current and $I_1$, $I_2$, and $I_3$ are the currents through R1, R2, and R3, respectively. To calculate the total current, simply add the individual branch currents by using the $I_t$ formula. Before calculating total current it will be necessary to calculate the individual branch currents by using Ohm's Law:

$$I_1 = \frac{E_a}{R1} = \frac{6\,V}{15\Omega} = .4 \text{ amps}$$

$$I_2 = \frac{E_a}{R2} = \frac{6\,V}{25\Omega} = .24 \text{ amps}$$

$$I_3 = \frac{E_a}{R3} = \frac{6\,V}{12\Omega} = .5 \text{ amps}$$

$$I_t = I_1 + I_2 + I_3$$

$$= .4\,A + .24\,A + .5\,A$$

$$= 1.14 \text{ amps}$$

5-67. In a parallel circuit, you have seen that:

$$I_t = I_1 + I_2 + I_3$$

By Ohm's Law, you may obtain the following relationships:

$$I_t = \frac{E_a}{R_t}$$

$$I_1 = \frac{E_1}{R1}$$

$$I_2 = \frac{E_2}{R2}$$

$$I_3 = \frac{E_3}{R3}$$

5-68. Substitute these values in the equation for total current.

$$\frac{E_a}{R_t} = \frac{E_1}{R1} + \frac{E_2}{R2} + \frac{E_3}{R3}$$

5-69. In a parallel circuit $E_a = E_1 = E_2 = E_3$. Therefore,

$$\frac{E_a}{R_t} = \frac{E_a}{R1} + \frac{E_a}{R2} + \frac{E_a}{R3}$$

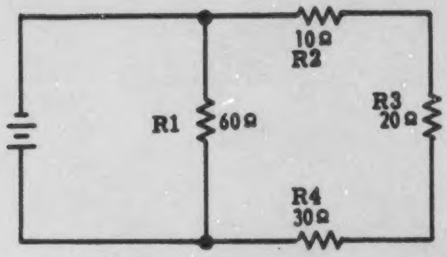
Divide through by $E_a$

$$\frac{1}{R_t} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

5-70. This equation is known as the reciprocal formula for finding the total or equivalent resistance of a parallel circuit. Another form of the equation may be obtained by solving for $R_t$. Thus,

$$R_t = \frac{1}{1/R1 + 1/R2 + 1/R3}$$

5-71. An analysis of the equation for total resistance in a parallel circuit reveals that $R_t$ is always less than the smallest resistive branch in a parallel circuit. Thus, a 10-ohm, a 20-ohm, and a 40-ohm resistor connected in parallel have a total resistance of less than 10 ohms.



REP4-925

Figure 5-21

5-72. If there are only two resistors in a parallel circuit, the reciprocal formula is:

$$\frac{1}{R_t} = \frac{1}{R1} + \frac{1}{R2}$$

5-73. This may be simplified still further to a formula called the product over the sum formula:

$$R_t = \frac{R1 \times R2}{R1 + R2}$$

5-74. The equivalent resistance of two resistors in parallel is equal to the product of the two resistors divided by their sum. For example, a 20-ohm resistor and a 30-ohm resistor in parallel are equivalent to a resistor of 12 ohms. This is found as follows:

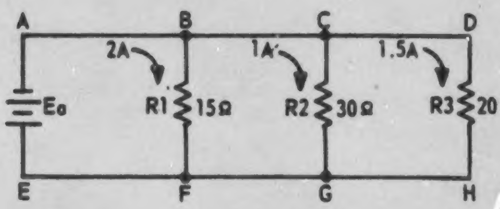
$$R_t = \frac{20 \times 30}{20 + 30} = \frac{600}{50} = 12 \text{ ohms}$$

5-75. The total resistance of any number of equal resistors connected in parallel is equal to the resistance of one resistor divided by the number of resistors. Expressed mathematically,

$$R_t = \frac{R}{N}$$

where $R_t$ is the total resistance, R is the resistance of one resistor, and N is the number of resistors.

5-76. For three 300-ohm resistors, this equation may be derived as follows:



REP4-926

Figure 5-22

$$\frac{1}{R_t} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

$$\frac{1}{R_t} = \frac{1}{300} + \frac{1}{300} + \frac{1}{300}$$

$$\frac{1}{R_t} = \frac{3}{300}$$

$$R_t = \frac{300}{3}$$

$$= 100 \text{ ohms}$$

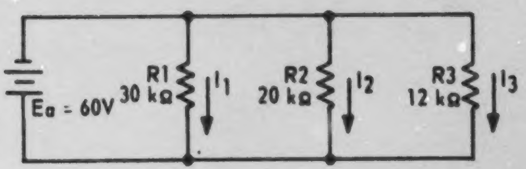
5-77. When one branch has more than one resistor, the first step will be to add the series resistance. See figure 5-21.

5-78. The total resistance of the outer branch (R2, R3 and R4) will be Re = 10+20+30=60 ohms. Because Re equals the value of R1, then the formula Rt = $\frac{R}{N}$ can be used to find the total resistance.

$$R_t = \frac{R}{N} = \frac{60\Omega}{2} = 30\Omega$$

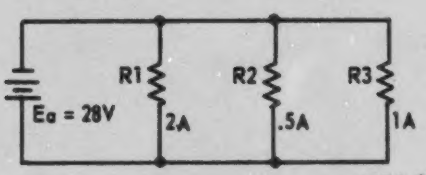
5-79. Quite often it will be necessary to apply Kirchhoff's Law, as well as Ohm's Law, when solving for unknown quantities in a parallel circuit. Using the circuit in figure 5-22, solve for the applied voltage.

5-80. Kirchhoff's voltage Law states that the sum of the voltage drops in a closed loop are equal to the applied voltage. In the circuit shown above there are three separate closed loops. They are ABFE, ACGE, and ADHE. Find the voltage drop in one loop, and you have the applied voltage. To understand this principle, solve loop ABFE by using Ohm's Law:



REP4-927

Figure 5-23



REP4-928

Figure 5-24

$$E_a = IR$$
$$= I_1R1$$
$$= 2\text{ A} \times 15\text{ ohms}$$
$$= 30\text{ volts}$$

5-81. Now, by using Ohm's Law, solve loops ACGE and ADHE.

$$E_a = IR$$
$$= I_2R2$$
$$= 1\text{ A} \times 30\text{ ohms}$$
$$= 30\text{ volts}$$

$$E_a = IR$$
$$= I_3R3$$
$$= 1.5\text{ A} \times 20\text{ ohms}$$
$$= 30\text{ volts}$$

5-82. A good point to remember when dealing with parallel resistive circuits is that the applied voltage is equal to the total voltage drop in any branch, or loop.

5-83. Using the circuit in figure 5-23, solve for the individual branch currents, when given the applied voltage, and the branch resistances. Using Kirchhoff's Law, you know that the voltage drop across each resistor is equal to the applied voltage. By using Ohm's Law, the current in each branch can be calculated.

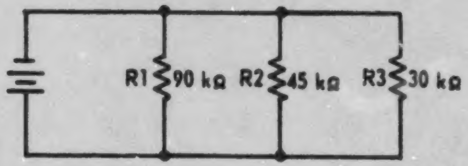
$$I_1 = \frac{E_a}{R1}$$
$$= \frac{60\text{ V}}{30\text{ k}\Omega}$$
$$= 2\text{ mA}$$

$$I_2 = \frac{E_a}{R2}$$
$$= \frac{60\text{ V}}{20\text{ k}\Omega}$$
$$= 3\text{ mA}$$

$$I_3 = \frac{E_a}{R3}$$
$$= \frac{60\text{ V}}{12\text{ k}\Omega}$$
$$= 5\text{ mA}$$

5-84. Again, knowing and applying a principle of Kirchhoff's voltage Law enables you to solve for the individual branch currents. Note, also, the fact that the highest current flows through the branch that contains the lowest resistance.

5-85. Using the circuit in figure 5-24, solve for individual branch resistances. The process is essentially the same as when you solved for branch currents. By Kirchhoff's Law, the voltage drop across each resistor is equal to the applied voltage. By using Ohm's Law, the resistance in each branch can be calculated.



REP4-929

Figure 5-25

$$R1 = \frac{E_a}{I_1}$$

$$= \frac{28\,V}{2\,A}$$

$$= 14 \text{ ohms}$$

$$R2 = \frac{E_a}{I_2}$$

$$= \frac{28\,V}{.5\,A}$$

$$= 56 \text{ ohms}$$

$$R3 = \frac{E_a}{I_3}$$

$$= \frac{28\,V}{1\,A}$$

$$= 28 \text{ ohms}$$

5-86. Perhaps the best method of showing how to apply these different formulas is to take an example of each and work it out step by step. Refer to the parallel circuit shown in figure 5-25. Because the resistors are of unequal value and the circuit contains more than two resistors, use the reciprocal formula to solve for total resistance.

$$R_t = \frac{1}{1/R1 + 1/R2 + 1/R3}$$

$$= \frac{1}{1/90\,k\Omega + 1/45\,k\Omega + 1/30\,k\Omega}$$

$$= \frac{1}{1/90\,k\Omega + 2/90\,k\Omega + 3/90\,k\Omega}$$

$$= \frac{1}{6/90\,k\Omega}$$

$$= \frac{90\,k\Omega}{6}$$

$$= 15\,k\Omega$$

5-87. Another method often used to calculate the total equivalent resistance using any number of resistors in parallel is to assume a convenient voltage across the parallel branch. The currents that would flow through each branch with the assumed voltage applied are then added to obtain the total current. The equivalent resistance is found by using Ohm's Law - dividing the assumed voltage by the total current.

5-88. For example, to find the total resistance of the circuit shown in figure 5-25, use an assumed voltage. Choose a voltage that is easily divisible by the value of each of the resistors. In this case, assume 90 volts is applied. Therefore:

$$I_1 = \frac{90\,V}{90\,k\Omega} = 1\,mA$$

$$I_2 = \frac{90V}{45\,k\Omega} = 2\,mA$$

$$I_3 = \frac{90\,V}{30\,k\Omega} = 3\,mA$$

Now add the branch currents:

$$I_t = I_1 + I_2 + I_3$$

$$= 1\,mA + 2\,mA + 3\,mA = 6\,mA$$

Divide total current into the assumed voltage to determine total resistance:

$$R_t = \frac{E_a}{I_t} = \frac{90\,V}{6\,mA} = 15\,k \text{ ohms}$$

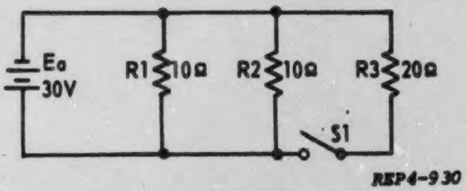


Figure 5-26

5-89. When an additional resistor is added to any parallel resistive circuit, the total resistance will decrease and total current will increase. To examine this relationship, refer to the circuit in figure 5-26.

5-90. First calculate total resistance and total current with R3 out of the circuit. S1 is open.

$$R_t = \frac{R}{N} = \frac{10\Omega}{2} = 5\Omega$$

$$I_t = \frac{E_a}{R_t} = \frac{30\text{ V}}{5\Omega} = 6\text{ amps}$$

5-91. Now insert R3 into the circuit by closing switch S1. Since the equivalent (Re) of R1 and R2 is 5 ohms, there are two unequal resistances in parallel. This situation requires the use of the product over the sum formula to calculate the total resistance.

$$R_t = \frac{R_e \times R3}{R_e + R3}$$

$$= \frac{5 \times 20}{5 + 20}$$

$$= \frac{100}{25}$$

$$= 4\Omega$$

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{30\text{ V}}{4\Omega}$$

$$= 7.5\text{ amps}$$

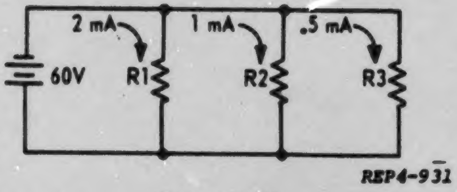


Figure 5-27

5-92. Thus, you can see that by adding a resistor in parallel, the total resistance decreased and the total current increased. By removing resistors, the opposite condition results.

5-93. The method of calculating the power dissipated in a parallel DC circuit is identical to the method used to calculate the power dissipated in a series DC circuit. Using the circuit in figure 5-27, determine the power dissipated by each resistor and the total power dissipated by the circuit.

5-94. Since the voltage and the individual branch currents, are given the power formula can be used in its original form: P = IE. The power dissipated by each resistor is equal to the current flowing through it times the voltage drop across it. Thus,

$$P_{R1} = I_1 \times E_1$$

$$= 2\text{ mA} \times 60\text{ V} = 120\text{ mW}$$

$$P_{R2} = I_2 \times E_2$$

$$= 1\text{ mA} \times 60\text{ V} = 60\text{ mW}$$

$$P_{R3} = I_3 \times E_3$$

$$= .5\text{ mA} \times 60\text{ V} = 30\text{ mW}$$

5-95. The total power dissipated by any circuit is always equal to the sum of the power dissipated by the individual resistors. Thus,

$$P_t = P_{R1} + P_{R2} + P_{R3}$$

$$= 120\text{ mW} + 60\text{ mW} + 30\text{ mW} = 210\text{ mW}$$

5-96. The total power dissipated by the circuit in figure 5-27 can also be calculated by multiplying total current times the applied voltage. To find total current, simply add the individual branch currents. Total current is equal to the sum of $I_1$ plus $I_2$ plus $I_3$ or 3.5 mA. Thus,

$$P = I \times E$$

$$= 3.5\,\text{mA} \times 60\,\text{V}$$

$$= 210\,\text{mW}$$

5-97. The power formula has two other forms, as learned in series resistive circuits. If the total current and total resistance are known, use this form of the basic formula:

$$P = I^2 \times R$$

This formula can be used to calculate individual branch powers or the total power when the voltage is unknown. Refer to the circuit shown in figure 5-28.

$$P_{R1} = (I_1)^2 \times R1$$

$$= (6\,\text{A})^2 \times 20\ \text{ohms}$$

$$= 720\,\text{W}$$

$$P_{R2} = (I_2)^2 \times R2$$

$$= (2\,\text{A})^2 \times 60\ \text{ohms}$$

$$= 240\,\text{W}$$

$$P_{R3} = (I_3)^2 \times R3$$

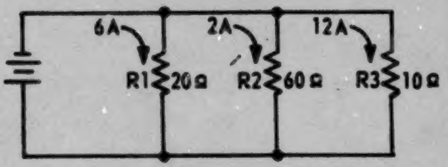
$$= (12\,\text{A})^2 \times 10\ \text{ohms}$$

$$= 1440\,\text{W}$$

$$P_t = P_{R1} + P_{R2} + P_{R3}$$

$$= 720\,\text{W} + 240\,\text{W} + 1440\,\text{W}$$

$$= 2400\,\text{W or } 2.4\,\text{kW}$$



REP4-932

Figure 5-28

5-98. The total power dissipated by the circuit in figure 5-28 can also be calculated by multiplying the total current squared times the total resistance. To find the total current, simply add the individual branch currents. To find the total resistance, use the reciprocal formula for three resistors. In this circuit a 20-ohm, a 60-ohm, and a 10-ohm resistor in parallel equals a total resistance of 6 ohms. Thus,

$$P_t = (I_t)^2 \times R_t$$

$$= (20\,\text{A})^2 \times 6\ \text{ohms}$$

$$= 400 \times 6$$

$$= 2400\,\text{W or } 2.4\,\text{kW}$$

5-99. If the applied voltage and the total resistance are known, use this form of the basic formula.

$$P = \frac{E^2}{R}$$

5-100. Referring to the circuit in figure 5-28 again, calculate the total power dissipated by the circuit. Before the above formula can be used, it will be necessary to determine the applied voltage. Since the current through any one resistor is known, as well as the ohmic value of that resistor, calculate the voltage drop across that resistor by using Ohm's Law. Once the voltage drop across any one resistor in a parallel circuit is known, the applied voltage is known. Calculate the voltage drop across R1 to determine the applied voltage.

$$E_a = E_{R1} = I_1 \times R1$$

$$= 6\,\text{A} \times 20\ \text{ohms}$$

$$= 120\,\text{V}$$

With an applied voltage of 120 V and a total resistance of 6 ohms, the total power dissipated by the circuit can now be calculated. Thus,

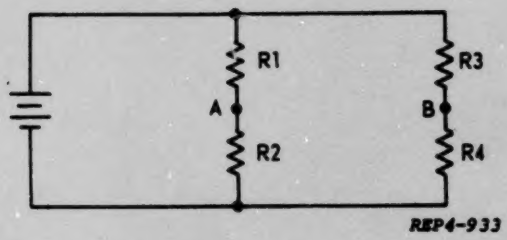


Figure 5-29

$$P_t = \frac{E_a^2}{R_t}$$

$$= \frac{(120\,V)^2}{6\,\Omega}$$

$$= 2400\,W \text{ or } 2.4\,kW$$

### 5-101. Characteristics of Parallel DC Circuits

a. The same voltage exists across each branch of a parallel circuit and is equal to the applied voltage. $E_a$ is common to all branches.

b. The current through a branch of a parallel network is directly proportional to the applied voltage and inversely proportional to the amount of resistance of the branch.

c. The total current of a parallel circuit is equal to the sum of the branch currents.

d. The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the circuit and is always less than the lowest resistance value.

e. The total power dissipated by a parallel circuit is equal to the sum of the individual power dissipations.

### 5-102. Resistive Bridge Circuits

5-103. Bridge circuits are frequently used in electronics where a signal from one device is used to control another device. They are used in fire control, weapons control, and bomb navigation systems. Some bridge circuits have fixed components while others contain adjustable components. Bridge circuits with variable components are used in very accurate test equipment. This lesson is confined to resistive, DC bridge circuits.

5-104. Figure 5-29 shows a parallel circuit with which we are already familiar. It has two paths for current flow. Note the two identifying points on the circuit, point A between resistors R1 and R2 and point B between resistors R3 and R4. Suppose you take points A and B and stretch the circuit. The result is a diamond shape.

5-105. To make a bridge circuit out of this diamond shape, some type of resistive load (the detecting device) must be connected between points A and B as shown in figure 5-30.

5-106. Perhaps you can see a relationship in the circuit already. If there is a difference of potential between points A and B, current will flow through the load device. The direction of current flow is determined by the polarity of voltage present at point A with respect to point B. On the other hand, if there is no difference of potential between points A and B, no current will flow through the load device. Quite often, when the bridge circuit is used in electronic test instruments,

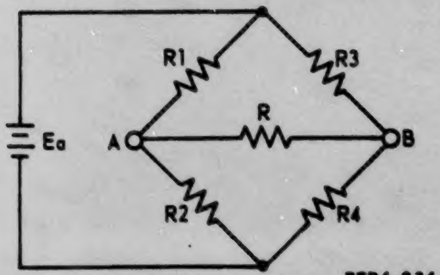


Figure 5-30

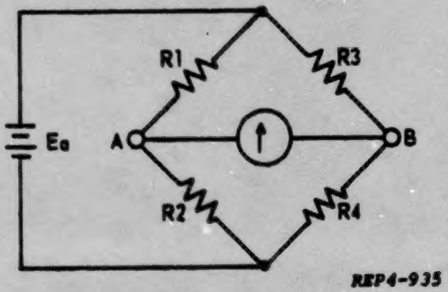


Figure 5-31

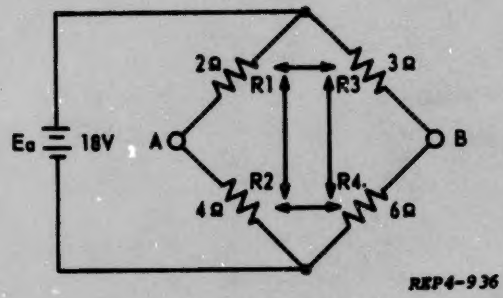


Figure 5-32

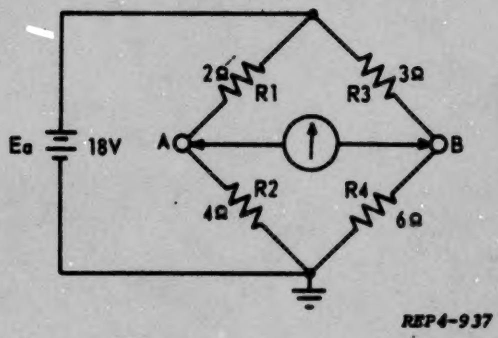


Figure 5-33

the load device is a very sensitive meter movement. Figure 5-31 shows a galvanometer connected between points A and B.

5-107. The galvanometer is a sensitive current-indicating meter which measures magnitude and direction of current flow. With no current flowing through the meter, the needle will point to zero. When the galvanometer is reading zero, the bridge circuit is said to be BALANCED. When the bridge is in a balanced condition, there is no difference of potential between point A and point B.

5-108. To show that the circuit in figure 5-32 is a balanced bridge, use a RATIO RELATIONSHIP. Using the ratio relationship, R1 is to R2 as R3 is to R4 or 2 ohms is to 4 ohms as 3 ohms is to 6 ohms. Setting this ratio up in mathematical form, we have:

$$\frac{R1}{R2} = \frac{R3}{R4}$$

or

$$\frac{2\Omega}{4\Omega} = \frac{3\Omega}{6\Omega}$$

By cross multiplication, 12 ohms equals 12 ohms. The bridge is balanced.

5-109. Note in figure 5-32 the relationship that exists between any two resistors in the vertical or horizontal plane:

$$\frac{R1}{R3} = \frac{R2}{R4}$$

and

$$\frac{R1}{R2} = \frac{R3}{R4}$$

In numbers,

$$\frac{2\Omega}{3\Omega} = \frac{4\Omega}{6\Omega}$$

and

$$\frac{2\Omega}{4\Omega} = \frac{3\Omega}{6\Omega}$$

5-110. Another method to determine if the bridge is balanced is to determine the potential difference between points A and B (figure 5-33). You could connect a voltmeter between these points, but instead find the answer by using Ohm's Law. In a parallel circuit, $E_a$ is the same in all branches. But you can see that R1 and R2 are in series with each other and that R3 and R4 are also in series with each other.

Step 1:

Find the resistance of Branch A and Branch B.

Branch A:

$$R_A = R1 + R2$$

$$= 2 \text{ ohms} + 4 \text{ ohms}$$

$$= 6 \text{ ohms}$$

Branch B:

$$R_B = R3 + R4$$

$$= 3 \text{ ohms} + 6 \text{ ohms}$$

$$= 9 \text{ ohms}$$

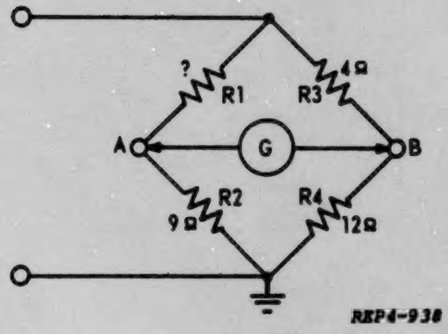


Figure 5-34

**Step 2:**

Find the current through Branch A and Branch B.

Branch A:

$$I_A = \frac{E}{R_A}$$

$$= \frac{18\,V}{6\,\Omega}$$

$$= 3 \text{ amps}$$

Branch B:

$$I_B = \frac{E}{R_B}$$

$$= \frac{18\,V}{9\,\Omega}$$

$$= 2 \text{ amps}$$

**Step 3:**

Compute the potential at point A and point B. A ground reference point has been added to the circuit shown in figure 5-33. With ground at this point, the potentials at points A and B are positive with respect to ground.

Voltage at point A:

$$E_A = I_A \times R2$$

$$= 3\,A \times 4 \text{ ohms}$$

$$= 12 \text{ volts}$$

Voltage at point B:

$$E_B = I_B \times R4$$

$$= 2\,A \times 6 \text{ ohms}$$

$$= 12 \text{ volts}$$

**Step 4:**

Find the voltage difference between point A and point B.

$$12V - 12V = 0 \text{ volts}$$

With 0 volts existing between the two points, no current will flow through the galvanometer. This is the condition of a balanced bridge.

5-111. Referring to the bridge circuit shown in figure 5-34, determine the value the unknown resistor must be to balance the bridge.

**Step 1:**

Set up the basic ratio formula and insert the known values.

$$\frac{R1}{R2} = \frac{R3}{R4}$$

or

$$\frac{R1}{9\Omega} = \frac{4\Omega}{12\Omega}$$

**Step 2:**

Solve for R1.

$$R1 \times 12 = 9 \text{ ohms} \times 4 \text{ ohms}$$

$$12(R1) = 36 \text{ ohms}$$

$$R1 = 3 \text{ ohms}$$

When R1 equals 3 ohms, the bridge is in a balanced condition. No difference of potential exists between points A and B. This balanced bridge condition is indicated by a zero reading on the galvanometer.

5-112. In the foregoing examples, you have been working with a balanced bridge circuit. Examine the characteristics of the UNBALANCED bridge circuit, in figure 5-35. A positive way to determine whether the bridge is balanced or unbalanced is to use the ratio formula.

$$\frac{R1}{R2} = \frac{R3}{R4}$$

or

$$\frac{7\Omega}{14\Omega} = \frac{3\Omega}{4\Omega}$$

By cross multiplication, 28 does not equal 42, therefore, the bridge is unbalanced. With the bridge unbalanced, a voltage exists between points A and B. This voltage can be determined by Ohm's Law.

Branch A:

$$R = 21 \text{ ohms}$$

$$I = \frac{E}{R}$$

$$= \frac{21\,V}{21\Omega}$$

$$= 1 \text{ amp}$$

Voltage at point A:

$$E = I \times R2$$

$$= 1\,A \times 14 \text{ ohms}$$

$$= 14 \text{ volts}$$

Branch B:

$$R = 7 \text{ ohms}$$

$$I = \frac{E}{R}$$

$$= \frac{21\,V}{7\Omega}$$

$$= 3 \text{ amps}$$

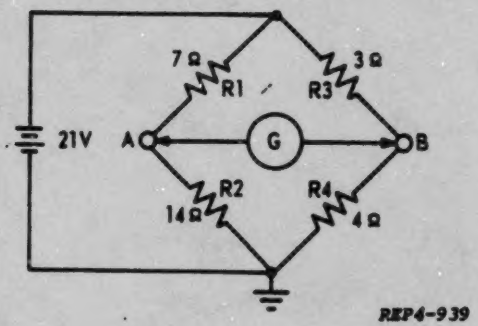


Figure 5-35

Voltage at point B:

$$E = I \times R4$$

$$= 3\,A \times 4 \text{ ohms}$$

$$= 12 \text{ volts}$$

Voltage between points A and B

$$14\,V - 12\,V = 2 \text{ volts}$$

The voltage between points A and B is 2 volts. Since point A is more positive than point B, current will flow from point B toward point A through the galvanometer. To balance the bridge circuit shown in figure 5-35, the size of R1, R2, R3, or R4 must change. Assume that R4 is to be changed. Again use the ratio:

$$\frac{R1}{R2} = \frac{R3}{R4}$$

or

$$\frac{7}{14} = \frac{3}{R4}$$

Solve for R4.

$$7 \times R4 = 14 \times 3$$

$$7(R4) = 42$$

$$R4 = 6 \text{ ohms}$$

Replace the 4-ohm resistor with a 6-ohm resistor and the bridge is again balanced. There will be no voltage between points A and B and the galvanometer will read zero.

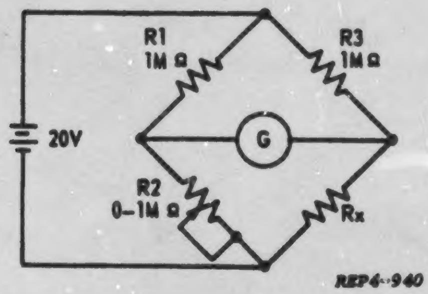


Figure 5-36

5-113. The principles of the bridge circuit has been used to build an instrument to measure unknown resistances. It is called a Wheatstone Bridge. Look at figure 5-36. R2 is variable and is connected to a dial that is calibrated to read ohms. $R_x$ is an unknown resistance. To find the value of Rx adjust R2 until the bridge is balanced, then read the value of R2 on the dial. Why is this true? In figure 5-36 notice that R1 is equal to R3. For the bridge to be balanced R2 must be equal to Rx. Therefore the dial reading of R2 gives the value of the unknown resistor, Rx.

5-114. The largest resistor that could be measured with the circuit shown in figure 5-36 is 1 megohm. The range of a Wheatstone Bridge is increased with the changes shown in figure 5-37.

When $R_x$ is less than 1 ohm, switch S1 is placed in the $R_a$ position. Then, resistor $R_a$ is adjusted to balance the bridge circuit. The size of $R_x$ is taken from the dial reading on resistor $R_a$. With a larger unknown resistor, switch S1 must be rotated to the position required to measure the unknown value. For example, assume that the unknown resistor is 900 k ohms. In this case switch S1 must be placed in the $R_e$ position, and the 1-megohm resistor must be adjusted for a readout.

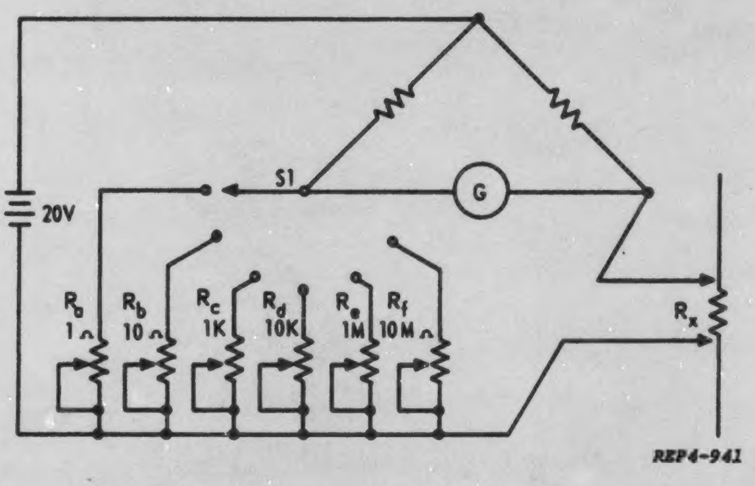


Figure 5-37

## 5-115. Series-Parallel Resistive Circuits

5-116. A series-parallel circuit is simply a group of parallel resistors connected in series with other resistors. A series resistor is one with total current ($I_t$) flowing through it, so it is easy to locate. The current distribution in a series-parallel circuit is shown below in figure 5-38. The total current leaving the negative side of the power source splits and has two paths to flow, $I_1$ and $I_2$, then it recombines for total current flow through $R_1$.

5-117. Any series-parallel circuit can be solved by following these six steps:

a. Find the equivalent resistance ($R_E$) of the parallel branches and draw the equivalent series circuit.

b. Add $R_E$ to the series resistance to get $R_t$.

c. Calculate $I_t$ using Ohm's Law ($I_t = E_a/R_t$).

d. Calculate voltage drops across series resistor and equivalent resistor ($E_{RE}$).

e. Calculate branch currents using $E_{RE}$ for the parallel branches.

f. Calculate power dissipation.

NOTE: When calculating total resistance always start with resistors that are furtherest from the power source.

5-118. Let's use these six steps to solve an example problem. (Refer to figure 5-39).

Step 1: Find the $R_E$ (equivalent resistance) of the parallel branches and draw the equivalent series circuit.

$$R_E = \frac{R2 \times R3}{R2 + R3}$$

$$= \frac{18k\Omega \times 9k\Omega}{18k\Omega + 9k\Omega}$$

$$= \frac{162 \times 10^6}{27 \times 10^3} = 6k \text{ ohms}$$

R2 and R3 are the parallel branches, and by using the product over the sum formula, we get an equivalent resistance ($R_E$) of 6k ohms. Now, draw an equivalent series circuit using $R_E$ in place of R2 and R3. (Refer to figure 5-40.)

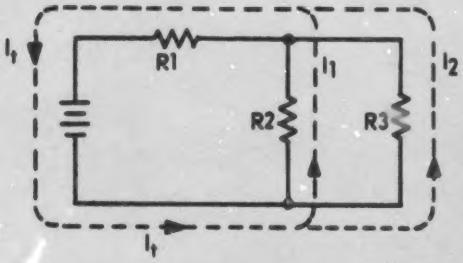


Figure 5-38

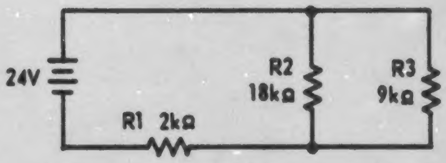


Figure 5-39

Step 2: Add $R_E$ to the series resistance (R1) to get $R_t$.

$$R_t = R1 + R_E$$

$$= 2k \text{ ohms} + 6k \text{ ohms}$$

$$= 8k \text{ ohms}$$

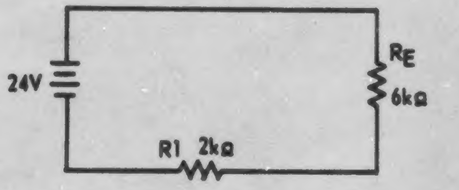


Figure 5-40

Step 3: Calculate $I_t$ using Ohm's Law:

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{24\,V}{8\,k\Omega}$$

$$= 3\,mA$$

Remember, when dividing by k ohms the answer will be in mA.

Step 4: Calculate the voltage drops across the series resistor and equivalent resistor $R_E$.

$$E_{R1} = I_t \times R1$$

$$= 3\,mA \times 2\,k\ ohms$$

$$= (3 \times 10^{-3}) \times (2 \times 10^{3})$$

$$= 6\,V$$

$$E_{RE} = I_t \times R_E$$

$$= 3\,mA \times 6\,k\ ohms$$

$$= (3 \times 10^{-3}) \times (6 \times 10^{3})$$

$$= 18\,V$$

The sum of the two voltage drops equals the applied voltage. Kirchhoff's voltage law is true.

$$E_a = E_{R1} + E_{RE}$$

$$24\,V = 6\,V + 18\,V$$

Step 5: Calculate branch currents using $E_{RE}$ for the parallel branches.

$$I_{R2} = \frac{E_{RE}}{R2}$$

$$= \frac{18\,V}{18\,k\Omega}$$

$$= 1\,mA$$

$$I_{R3} = \frac{E_{RE}}{R3}$$

$$= \frac{18\,V}{9\,k\Omega}$$

$$= 2\,mA$$

Total current equals the sum of the branch currents.

$$I_t = I_{R2} + I_{R3}$$

$$3\,mA = 1\,mA + 2\,mA$$

Step 6: Calculate power dissipation.

$$P_{R1} = I_t \times E_{R1}$$

$$= 3\,mA \times 6\,V$$

$$= 18\,mW$$

$$P_{R2} = I_{R2} \times E_{R2}$$

$$= 1\,mA \times 18\,V$$

$$= 18\,mW$$

$$P_{R3} = I_{R3} \times E_{R3}$$

$$= 2\,mA \times 18\,V$$

$$= 36\,mW$$

The sum of the power dissipated by each resistor equals the total power dissipated.

$$P_t = P_{R1} + P_{R2} + P_{R3}$$

$$= 18\,mW + 18\,mW + 36\,mW$$

$$= 72\,mW$$

Or $P_t = I_t \times E_a$

$$= 3\,mA \times 24\,V$$

$$= 72\,mW$$

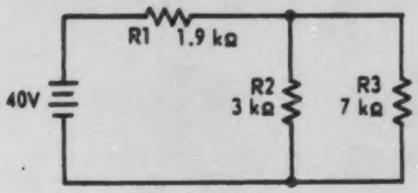


Figure 5-41

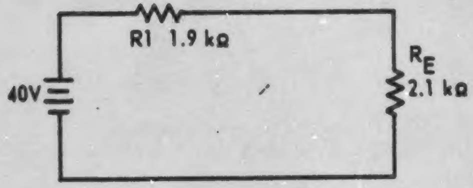


Figure 5-42

5-119. Now work another example of a series-parallel circuit using the six steps. (Refer to figure 5-41).

Step 1: Find $R_E$ of the parallel branches and redraw as a series circuit.

$$R_E = \frac{R2 \times R3}{R2 + R3}$$

$$= \frac{3k\Omega \times 7k\Omega}{3k\Omega + 7k\Omega}$$

$$= \frac{21 \times 10^6}{10 \times 10^3}$$

$$= 2.1\text{k ohms}$$

The equivalent series circuit would appear as shown in figure 5-42.

Step 2: Find $R_t$ by adding R1 and $R_E$.

$$R_t = R1 + R_E$$

$$= 1.9\text{k ohms} + 2.1\text{k ohms}$$

$$= 4\text{k ohms}$$

Step 3: Calculate $I_t$ using Ohm's Law.

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{40\,V}{4k\Omega}$$

$$= 10\,mA$$

Step 4: Calculate voltage drops using Ohm's Law.

$$E_{R1} = I_t \times R1$$

$$= 10\,mA \times 1.9\text{k ohms}$$

$$= (10 \times 10^{-3}) \times (1.9 \times 10^3)$$

$$= 19\,V$$

$$E_{RE} = I_t \times R_E$$

$$= 10\,mA \times 2.1\text{k ohms}$$

$$= (10 \times 10^{-3}) \times (2.1 \times 10^3)$$

$$= 21\,V$$

Step 5: Calculate branch currents using $E_{RE}$ as the common voltage for the parallel branches.

$$I_{R2} = \frac{E_{RE}}{R2}$$

$$= \frac{21\,V}{(3 \times 10^3)\Omega}$$

$$= 7 \times 10^{-3}\,A$$

$$= 7\,mA$$

$$I_{R3} = \frac{E_{RE}}{R3}$$

$$= \frac{21\,V}{(7 \times 10^3)\Omega}$$

$$= 3 \times 10^{-3}\,A$$

$$= 3\,mA$$

NOTE: The sum of the branch currents equals the total current of 10 mA.

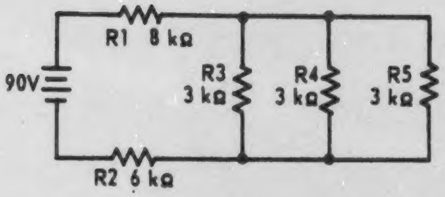


Figure 5-43

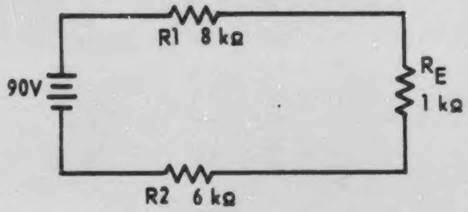


Figure 5-44

Step 6: Calculate power dissipation. Use the $I^2R$ formula to calculate power.

$$P_{R1} = (I_t)^2 \times R1$$

$$= (10\,mA)^2 \times 1.9\,k\ ohms$$

$$= (10 \times 10^{-3})^2 \times (1.9 \times 10^3)$$

$$= (100 \times 10^{-6}) \times (1.9 \times 10^3)$$

$$= 190 \times 10^{-3}\,W$$

$$= 190\,mW$$

$$P_{R2} = (I_{R2})^2 \times R2$$

$$= (7\,mA)^2 \times 3\,k\ ohms$$

$$= (7 \times 10^{-3})^2 \times (3 \times 10^3)$$

$$= (49 \times 10^{-6}) \times (3 \times 10^3)$$

$$= 147 \times 10^{-3}\,W$$

$$= 147\,mW$$

$$P_{R3} = (I_{R3})^2 \times R3$$

$$= (3 \times 10^{-3})^2 \times (7 \times 10^3)$$

$$= (9 \times 10^{-6}) \times (7 \times 10^3)$$

$$= 63 \times 10^{-3}\,W$$

$$= 63\,mW$$

$$P_t = P_{R1} + P_{R2} + P_{R3}$$

$$= 190\,mW + 147\,mW + 63\,mW$$

$$= 400\,mW$$

Or

$$P_t = I_t^2 \times R_t$$

$$= (10\,mA)^2 \times 4k\ ohms$$

$$= (10 \times 10^{-3})^2 \times (4 \times 10^3)$$

$$= (100 \times 10^{-6}) \times (4 \times 10^3)$$

$$= 400 \times 10^{-3}\,W$$

$$= 400\,mW$$

5-120. Next solve a series-parallel circuit containing three parallel resistors and two series resistors. (Refer to figure 5-43).

Step 1. Find $R_E$ of parallel branches and redraw the circuit.

$$R_E = \frac{R}{N}$$

$$= \frac{3k\Omega}{3}$$

$$= 1\,k\ ohm$$

The equivalent series circuit would appear as shown in figure 5-44.

Step 2: Find $R_t$ by adding $R_E$ and series resistors.

$$R_t = R1 + R2 + R_E$$

$$= 8k\ ohms + 6k\ ohms + 1\,k\ ohm$$

$$= 15\,k\ ohms$$

Step 3: Calculate $I_t$ using Ohm's Law.

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{90\,\text{V}}{15\,\text{k}\Omega}$$

$$= 6\,\text{mA}$$

Step 4: Calculate voltage drops across the resistors in the equivalent series circuit.

$$E_{R1} = I_t \times R1$$

$$= 6\,\text{mA} \times 8\,\text{k ohms}$$

$$= 48\,\text{V}$$

$$E_{R2} = I_t \times R2$$

$$= 6\,\text{mA} \times 6\,\text{k ohms}$$

$$= 36\,\text{V}$$

$$E_{RE} = I_t \times R_E$$

$$= 6\,\text{mA} \times 1\,\text{k ohm}$$

$$= 6\,\text{V}$$

The sum of these three voltage drops equals the applied voltage in accordance with Kirchhoff's voltage law.

Step 5: Calculate branch currents using $E_{RE}$ for the parallel branches.

$$I_{R3} = \frac{E_{RE}}{R3}$$

$$= \frac{6\,\text{V}}{3\,\text{k}\Omega}$$

$$= 2\,\text{mA}$$

$$I_{R4} = \frac{E_{RE}}{R4}$$

$$= \frac{6\,\text{V}}{3\,\text{k}\Omega}$$

$$= 2\,\text{mA}$$

$$I_{R5} = \frac{E_{RE}}{R5}$$

$$= \frac{6\,\text{V}}{3\,\text{k}\Omega}$$

$$= 2\,\text{mA}$$

The sum of the three branch currents equals the total current of 6 mA.

Step 6: Calculate power dissipation.

$$P_{R1} = I_t \times E_{R1}$$

$$= 6\,\text{mA} \times 48\,\text{V}$$

$$= 288\,\text{mW}$$

$$P_{R2} = I_t \times E_{R2}$$

$$= 6\,\text{mA} \times 36\,\text{V}$$

$$= 216\,\text{mW}$$

$$P_{R3} = I_{R3} \times E_{R3}$$

$$= 2\,\text{mA} \times 6\,\text{V}$$

$$= 12\,\text{mW}$$

$$P_{R4} = I_{R4} \times E_{R4}$$

$$= 2\,\text{mA} \times 6\,\text{V}$$

$$= 12\,\text{mW}$$

$$P_{R5} = I_{R5} \times E_{R5}$$

$$= 2\,\text{mA} \times 6\,\text{V}$$

$$= 12\,\text{mW}$$

$$P_t = P_{R1} + P_{R2} + P_{R3} + P_{R4} + P_{R5}$$

$$= 288\,\text{mW} + 216\,\text{mW} + 12\,\text{mW} + 12\,\text{mW} + 12\,\text{mW}$$

$$= 540\,\text{mW}$$

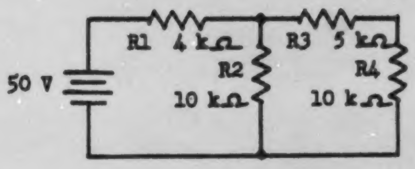


Figure 5-45

Or

$$P_t = I_t \times E_a$$

$$= 6\,\text{mA} \times 90\,\text{V}$$

$$= 540\,\text{mW}$$

5-121. One final example will complete your study of series-parallel circuits. (Refer to figure 5-45).

Step 1: Find $R_E$ of the parallel branches, then redraw equivalent series circuits.

NOTE: There are two series resistors, R3 and R4, in the last branch.

When a parallel branch has more than one resistor in it, you add the resistors together to get the total resistance of that branch. Then use that sum to solve for $R_E$.

$$R_E = \frac{R2 \times (R3 + R4)}{R2 + (R3 + R4)}$$

$$= \frac{10\,k\Omega \times (5\,k\Omega + 10\,k\Omega)}{10\,k\Omega + (5\,k\Omega + 10\,k\Omega)}$$

$$= \frac{10\,k\Omega \times 15\,k\Omega}{10\,k\Omega + 15\,k\Omega}$$

$$= \frac{(10 \times 10^3) \times (15 \times 10^3)}{(10 \times 10^3) + (15 \times 10^3)}$$

$$= \frac{150 \times 10^6}{25 \times 10^3}$$

$$= 6 \times 10^3 \text{ or } 6\,k \text{ ohms}$$

The equivalent series circuit will appear as shown. (Refer to figure 5-46.)

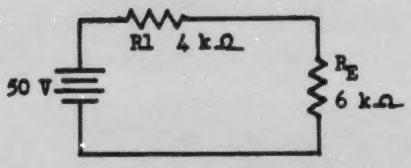


Figure 5-46

Step 2: Find $R_t$.

$$R_t = R1 + R_E$$

$$= 4\,k \text{ ohms} + 6\,k \text{ ohms}$$

$$= 10\,k \text{ ohms}$$

Step 3: Calculate $I_t$.

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{50\,\text{V}}{10\,k\Omega}$$

$$= 5\,\text{mA}$$

Step 4: Calculate the voltage drops.

$$E_{R1} = I_t \times R1$$

$$= 5\,\text{mA} \times 4\,k \text{ ohms}$$

$$= 20\,\text{V}$$

$$E_{RE} = I_t \times R_E$$

$$= 5\,\text{mA} \times 6\,k \text{ ohms}$$

$$= 30\,\text{V}$$

Step 5: Calculate branch currents:

$$I_{R2} = \frac{E_{RE}}{R2}$$

$$= \frac{30\,\text{V}}{10\,k\Omega}$$

$$= 3\,\text{mA}$$

$$I_{R3} + R4 = \frac{E_{RE}}{R3 + R4}$$

$$= \frac{30\,V}{15\,k\Omega}$$

$$= 2\,mA$$

Step 6: Calculate power dissipation.

$$P_{R1} = I_t \times E_{R1}$$

$$= 5\,mA \times 20\,V$$

$$= 100\,mW$$

$$P_{R\,2} = I_{R2} \times E_{R2}$$

$$= 3\,mA \times 30\,V$$

$$= 90\,mW$$

To determine the power dissipation for R3 and R4, first calculate the voltage drop across R3 and R4. $I_{R3}$ and $I_{R4}$ are the same current, 2 mA.

$$E_{R3} = I_{R3} \times R3$$

$$= 2\,mA \times 5\,k\ ohms$$

$$= 10\,V$$

$$E_{R4} = I_{R4} \times R4$$

$$= 2\,mA \times 10\,k\ ohms$$

$$= 20\,V$$

Now calculate $P_{R3}$ and $P_{R4}$:

$$P_{R3} = I_{R3} \times E_{R3}$$

$$= 2\,mA \times 10\,V$$

$$= 20\,mW$$

$$P_{R4} = I_{R4} \times E_{R4}$$

$$= 2\,mA \times 20\,V$$

$$= 40\,mW$$

$$P_t = P_{R1} + P_{R2} + P_{R3} + P_{R4}$$

$$= 100\,mW + 90\,mW + 20\,mW + 40\,mW$$

$$= 250\,mW$$

Or

$$P_t = I_t \times E_a$$

$$= 5\,mA \times 50\,V$$

$$= 250\,mW$$

## Chapter 6

## VOLTAGE DIVIDERS

6-1. Unlike the situation in the home, where practically all electrical appliances operate at the same voltage, radio and radar sets require several different values of voltage, even the small transistor radio requires more than one value of voltage. It is impractical to have a separate power source for each value of voltage required, especially since some electronic systems require dozens of different voltage values. A device which makes it possible to obtain more than one voltage from a single power source is known as a voltage divider.

6-2. A simple voltage divider, whose purpose is to provide voltage values other than the source voltage, is composed of a number of resistors in series with a power source as shown in figure 6-1. This circuit is simply a series circuit. It has three resistors connected across a source of voltage. Taps are provided and identified as B and C. In addition to the taps, a ground reference point has been added to the circuit. The applied voltage is available at point D.

6-3. With the values shown in figure 6-1, it is easy to see that there is a total resistance of 30 ohms. The applied voltage is 30 volts (point D). By using the Ohm's Law (I=E divided by R), 1 amp of current will be flowing through the voltage divider network. This 1 amp of current will develop a voltage of 5 volts across the 5-ohm resistor, 10 volts across the 10-ohm resistor, and 15 volts across the 15-ohm resistor. The voltage present at point A with respect to ground is 0 volts. The voltage at tap B with respect to ground is 5 volts. The voltage at tap C with respect to ground is 15 volts (5V + 10V). The voltage at point D with respect to ground is 30 volts (5V + 10V + 15V).Note the voltage at point D is the applied voltage. Thus, from one common power source it is possible to obtain several different values of voltage.

6-4. Examine the voltage divider circuit shown in figure 6-2 and see the different values of voltage that can be supplied. By summing the resistors, the total resistance is 100 ohms. With 200 volts applied to the

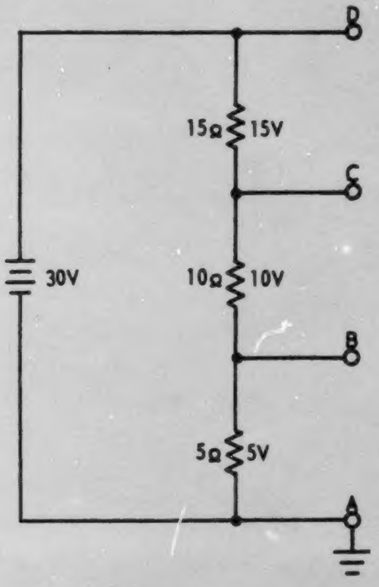


Figure 6-1

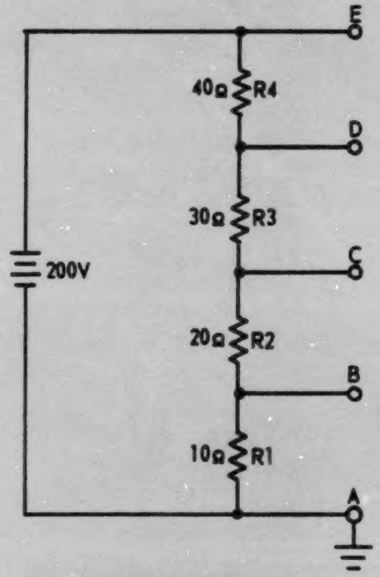


Figure 6-2

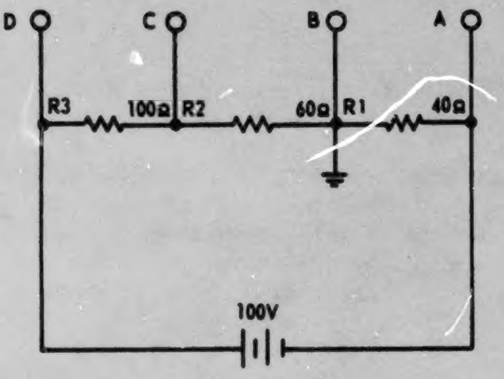


Figure 6-3

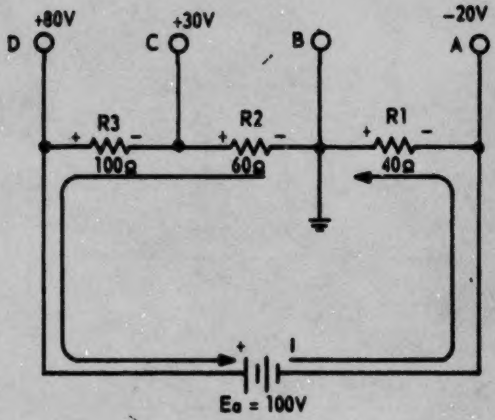


Figure 6-4

circuit, the current is 2 amps. The voltage drop across each resistor is as follows:

$$E_{R1} = I \times R1$$
$$= 2\,A \times 10 \text{ ohms}$$
$$= 20\,V$$

$$E_{R2} = I \times R2$$
$$= 2\,A \times 20 \text{ ohms}$$
$$= 40\,V$$

$$E_{R3} = I \times R3$$
$$= 2\,A \times 30 \text{ ohms}$$
$$= 60\,V$$

$$E_{R4} = I \times R4$$
$$= 2\,A \times 40 \text{ ohms}$$
$$= 80\,V$$

6-5. Now see what voltage is available at each tap with respect to ground. Between tap B and ground, there is 20 volts. Between tap C and ground, there is 60 volts. (Remember, always add the voltage drops from ground to the desired tap.) Between tap E and ground, there is 200 volts or the applied voltage.

6-6. Up to this point, you have studied voltage divider circuits that have one side of the power supply grounded. Now, move the ground from one side of the power supply to some other point on the voltage divider. See figure 6-3. By adding resistor values, the total resistance is 200 ohms. With a 100-volt power supply, current will be .5 amps. Figure the voltage drops.

$$E_{R1} = I \times R1$$
$$= .5\,A \times 40 \text{ ohms}$$
$$= 20\,V$$

$$E_{R2} = I \times R2$$
$$= .5A \times 60 \text{ ohms}$$
$$= 30\,V$$

$$E_{R3} = I \times R3$$
$$= .5\,A \times 100 \text{ ohms}$$
$$= 50\,V$$

6-7. The voltage drop across R1 is 20 volts. Since the tap at point A is connected to the negative side of the battery, the voltage at point A is 20 volts negative with respect to ground. See figure 6-4. Resistors R2 and R3 are connected to the positive side of the battery. Thus, the voltages at points C and D will be positive with respect to ground. The voltage drop across R2 makes point C 30 volts positive. The voltage at point D will be equal to the voltage drop across R3 and R2 or 80 volts positive.

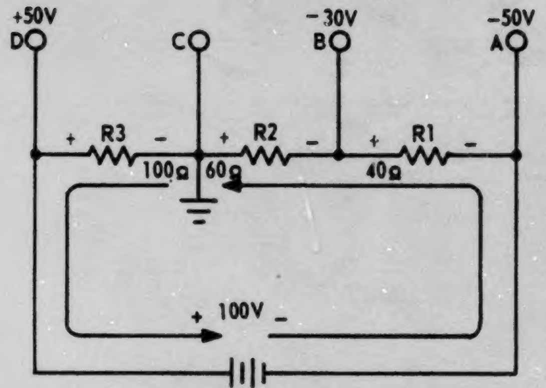


Figure 6-5

6-8. Another way to determine the polarity of a voltage drop with respect to ground in a voltage divider is to trace the direction of electron flow. This method of determining polarity is shown in figure 6-5. If current is flowing from a point toward ground, the voltage at that point will be negative with respect to ground. Since the current flowing through R1 is flowing from point A toward ground, the voltage at point A is negative. If current is flowing toward a point away from ground, the voltage at that point will be positive with respect to ground. Since the current flowing through R3 is flowing toward point D and away from ground, the voltage at point D is positive with respect to ground.

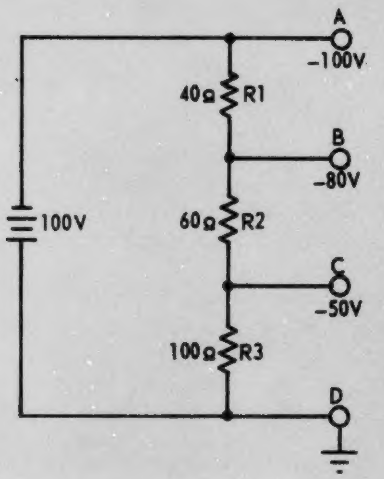


Figure 6-6

6-9. With the arrangement shown in figure 6-5, the voltage at point A is negative 50 volts; at point B, negative 30 volts; and at point D, positive 50 volts. Notice that figure 6-5 is the same circuit as figure 6-4, except the ground was moved from point B to point C. By merely changing the ground point, an entirely different set of voltages exist at the taps with respect to ground.

6-10. Now refer to the voltage divider circuit shown in figure 6-6. The ground has now been moved to point D. The voltage drop across each resistor is still the same as in figure 6-5, but the voltage available at each tap is different. The voltage at point A is -100 volts, at point B is -80 volts, and at point C is -50 volts with respect to ground.

6-11. Quite often in electronic equipment, the ground symbol not only represents the reference point but it also denotes the metal chassis. The value of using the metal chassis for ground is noted when considering economy, ease of circuit construction, and ease of making electrical meausrements. When completing each electrical circuit, common points are connected directly to the metal chassis; current flows through the metal chassis (conductor) to reach other points of the circuit. An example of using the chassis as ground is illustrated in figure 6-7.

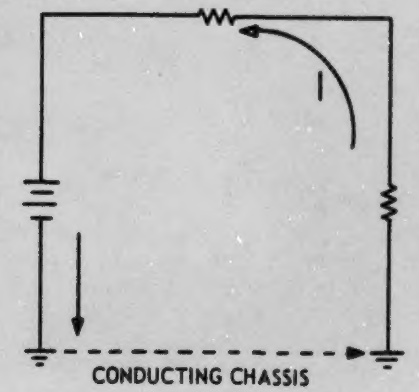


Figure 6-7

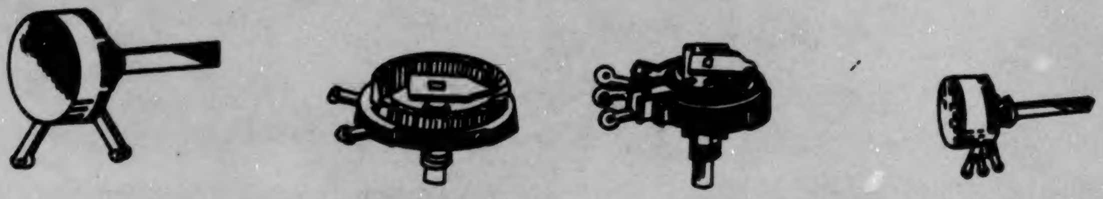


Figure 6-8

### 6-12. Rheostats and Potentiometers

6-13. Quite often a voltage divider network will make use of a variable resistor. The variable resistor is one of two types. One is called a RHEOSTAT and the other is called a POTENTIOMETER. Both types are shown in figure 6-8. There is a slight difference between them. Rheostats have two connections, one for the resistance element and one for the wiper arm. The potentiometer has three connections, two for the element and one for the wiper arm. Rheostats and potentiometers have a wide range of values.

6-14. A rheostat is a variable resistor which may be used as a control to vary the amount of CURRENT which flows through a voltage divider. A typical circuit in which a rheostat is used is shown in figure 6-9. Since the rheostat controls the current, it will determine the voltage drop between point X and ground.

6-15. Examine the schematic to see how the rheostat performs its function. As the slider arm is moved from A toward B, the amount of resistance (AB) in the circuit is increased. Since the rheostat and the fixed resistor are in series, the total resistance of the circuit also increases. The total current in the circuit, therefore, decreases. By a similar analysis, as the slider arm is moved toward A, the total resistance decreases and current increases.

6-16. Assign values to the circuit components in figure 6-9 and calculate the total resistance, total current, and voltage drop across R1 when the rheostat arm is first in position A and then in position B.

Given:

Applied voltage = 12 V

Rheostat value = 20 ohms

Fixed resistance = 80 ohms

Solution (wiper arm at A):

$R_t$ = rheostat resistance + fixed resistance

= 0 ohms + 80 ohms

= 80 ohms

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{12\text{ V}}{80\,\Omega}$$

= .15 amps

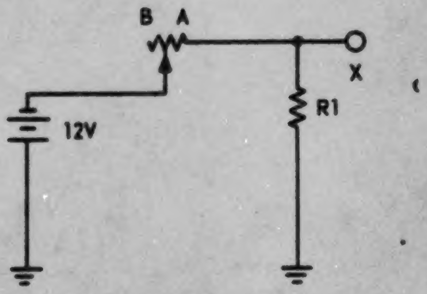


Figure 6-9

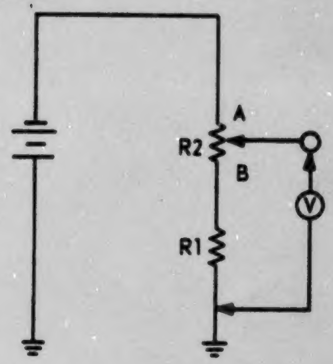


Figure 6-10

$E_{R1} = IR1$

$= .15\text{ A} \times 80\text{ ohms}$

$= 12\text{ V}$

Solution (wiper arm at B):

$R_t$ = rheostat resistance + fixed resistance

$= 20\text{ ohms} + 80\text{ ohms}$

$= 100\text{ ohms}$

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{12\text{ V}}{100\,\Omega}$$

$= .12$ amps

$E_{R1} = IR1$

$= .12\text{ A} \times 80\text{ ohms}$

$= 9.6\text{ V}$

6-17. From the above example it is evident that the voltage drop across R1 will decrease from 12 V to 9.6 V as the arm of the rheostat is turned from position A to position B. Note as total resistance increased, total current decreased. This decrease in current causes the voltage drop across R1 to decrease.

6-18. A potentiometer is a variable resistor used to vary the amount of VOLTAGE applied to an electrical device or circuit. A typical circuit in which a potentiometer is used is shown in figure 6-10.

6-19. Examine the schematic to see how the potentiometer performs its function. As the slider arm of R2 is moved from A to B, the amount of resistance in the basic circuit does not change. If resistance does not change, the current will not change. However, if a voltmeter is connected in the circuit as shown, a change in voltage would be noted as the arm is moved.

6-20. Assign values to the circuit components in figure 6-10 and determine the change in voltage as the arm of potentiometer R2 is moved from position A to position B.

Given: $E_a = 12\text{ V}$

$R1 = 80\text{ ohms}$

$R2 = 20\text{ ohms}$

Solution: $R_t = R1 + R2$

$= 80\text{ ohms} + 20\text{ ohms}$

$= 100\text{ ohms}$

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{12\text{ V}}{100\,\Omega}$$

$= .12\text{ A}$

$E_{R1} = I_t \times R1$

$= .12\text{ A} \times 80\text{ ohms}$

$= 9.6\text{ V}$

$E_{R2} = I_t \times R2$

$= .12\text{ A} \times 20\text{ ohms}$

$= 2.4\text{ V}$

6-21. When the arm of the potentiometer is in position A, the voltmeter will read the voltage drop across R1 and R2. In formula form:

$$E_a = E_{R1} + E_{R2}$$
$$= 9.6\,V + 2.4\,V$$
$$= 12\,V$$

6-22. When the arm of the potentiometer is in position B, the voltmeter will read the voltage drop across R1. In formula form:

$$E_B = E_{R1}$$
$$= 9.6\,V$$

6-23. It is now possible to obtain any desired voltage between 12V and 9.6V by simply moving the arm of the potentiometer to some point between point A and point B.

6-24. Using a potentiometer as a voltage divider provides a means of obtaining a variable voltage from a fixed voltage source. The potentiometer is one of the most common controls found in electronics. The volume control on a radio receiver and the brightness control on a television receiver are examples of its use. In choosing a potentiometer for a given purpose, follow the same rules for a resistor. Select the proper ohmic value and power rating.

6-25. Rheostats and potentiometers are constructed of a resistance material over which a sliding contact moves. The resistance may be distributed in many ways; the type of distribution determines the classification of the control as LINEAR or TAPERED. The linear control has its resistance evenly distributed over it's entire length. The tapered control has more resistance per unit length at one end than it has at the other. As an example, one-half turn of a linear control results in one-half of the total resistance between one end and the slider, while one-half turn of a tapered control may result in one-tenth (or any fraction) of the total resistance between one end and the slider.

6-26. Tapered controls are used to perform a specific job. The volume control on your radio is a tapered control. The taper is used to compensate for the way the human ear responds to the intensity of sound. Most volume controls are constructed so that the midpoint of the control divides the resistance into one-tenth and nine-tenths parts.

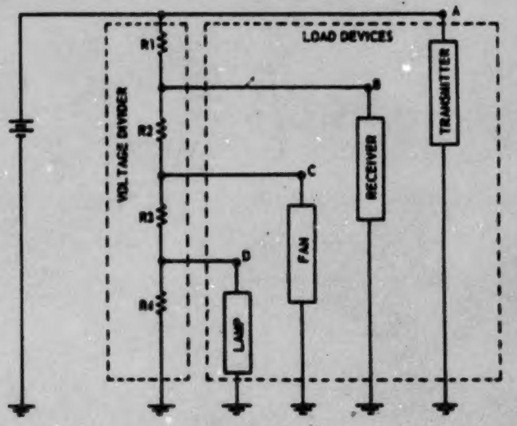


Figure 6-11

## 6-27. Loaded Voltage Dividers

6-28. A load device is defined as any component, mechanical or electrical, that consumes power as it performs its function. A resistor is often used as a load device. We must distinguish between the terms "load device" and "load." LOAD MEANS CURRENT. A light load means that a low value of current is being drawn from the power source or battery. A heavy load means that a high value of current is being drawn from the power source or battery. It stands to reason, then, that the ohmic value of the load device will determine the amount of load placed on a given voltage source. Placing the load device across a voltage divider creates a LOADED voltage divider circuit.

6-29. Figure 6-11 illustrates a loaded voltage divider circuit with four different load devices: a radio transmitter between point A and ground, a radio receiver between point B and ground, a fan motor between point C and ground, and a lamp between point D and ground. Careful inspection of this loaded voltage divider circuit shows it to be a series-parallel circuit.

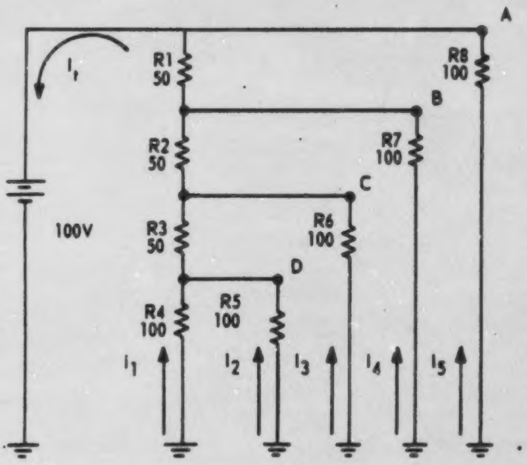


Figure 6-12

6-30. To calculate the current and the voltage within a voltage divider, use Kirchhoff's Laws. The current law states that the sum of the currents entering any point in a circuit will equal the sum of the currents leaving that point. The voltage law states that the sum of the voltage drops around a closed loop will be equal to the applied voltage. Keep these laws in mind while you work with voltage dividers. The current drawn from the power source divides between the voltage divider and load devices; it unites again as it returns to the power source. The voltage divider, with the power supply, form a closed loop, and the sum of the voltage drops along the divider will equal the applied voltage. The voltage across the each load device will equal the voltage present at the tap on the divider. As shown in figure 6-11, the voltage dropped across R4 is the voltage present at point D with respect to ground. Since the lamp is connected to point D on the divider, the voltage dropped across R4 is the same voltage that is applied across the lamp.

6-31. Take the voltage divider circuit shown in figure 6-12 and solve for the voltage at each point. The divider consists of four resistors in series identified as R1, R2, R3, and R4. Each load device is represented by a resistor identified as R5, R6, R7, and R8. Before solving for individual voltage drops, calculate total resistance and total current.

6-33. The combined effect of the individual load resistors and the voltage divider resistors can be solved by starting at the inside of the circuit and working out. Solve for the total resistance of the circuit in four steps.

Step 1 (figure 6-13):

$$Ra = \frac{R4 \times R5}{R4 + R5}$$

$$= \frac{100 \times 100}{100 + 100}$$

$$= 50 \text{ ohms}$$

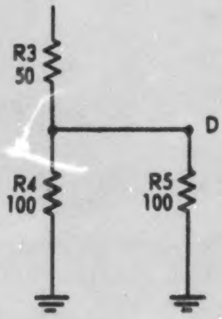


Figure 6-13

Step 2 (figure 6-14):

$$Rb = \frac{(Ra + R3) \times R6}{(Ra + R3) + R6}$$

$$= \frac{(50 + 50) \times 100}{(50 + 50) + 100}$$

$$= 50 \text{ ohms}$$

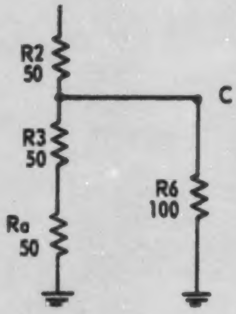


Figure 6-14

Step 3 (figure 6-15):

$$Rc = \frac{(Rb + R2) \times R7}{(Rb + R2) + R7}$$

$$= \frac{(50 + 50) \times 100}{(50 + 50) + 100}$$

$$= 50 \text{ ohms}$$

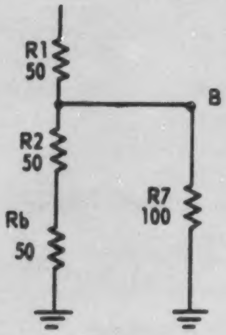


Figure 6-15

Step 4 (figure 6-16):

$$R_t = \frac{(Rc + R1) \times R8}{(Rc + R1) + R8}$$

$$= \frac{(50 + 50) \times 100}{(50 + 50) + 100}$$

$$= 50 \text{ ohms}$$

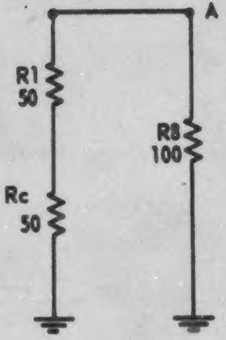


Figure 6-16

6-33. With the applied voltage and total resistance known, total current can be calculated by Ohm's Law.

$$I_t = \frac{E_a}{R_t} = \frac{100\text{ V}}{50\,\Omega} = 2\text{ A}$$

6-34. With the total current known, apply Kirchhoff's Laws and Ohm's Law to solve for individual branch currents and the voltage at each point along the divider with respect to ground. Figure 6-17 shows the individual paths of current through the divider circuit. The total current in the circuit is equal to the sum of the individual branch currents, or:

$$I_t = I_{R4} + I_{R5} + I_{R6} + I_{R7} + I_{R8}$$

6-35. To determine network RESISTANCE, you worked from the inside. To determine voltages, start with the outermost load device. The voltage across resistor R8 (point A with respect to ground) is the source voltage. Use Ohm's Law to find the current through R8, then solve for the remaining currents, as indicated in figure 6-17.

6-36. The following steps are shown as a method of determining the voltage at each point along the divider. Use figures 6-17 and 6-18 as an aid.

Step 1:

$$E_a = \text{source voltage} = 100\text{ V}$$

$$I_{R8} = \frac{E_a}{R8} = \frac{100\text{ V}}{100\,\Omega} = 1\text{ A}$$

Step 2:

$$I_{R1} = I_t - I_{R8} = 2\text{ A} - 1\text{ A} = 1\text{ A}$$

$$E_{R1} = I_{R1} \times R1 = 1\text{ A} \times 50\text{ ohms} = 50\text{ V}$$

$$E_B = E_a - E_{R1} = 100\text{ V} - 50\text{ V} = 50\text{ V}$$

$$I_{R7} = \frac{E_B}{R7} = \frac{50\text{ V}}{100\,\Omega} = .5\text{ A}$$

Step 3:

$$I_{R2} = I_{R1} - I_{R7} = 1\text{ A} - .5\text{ A} = .5\text{ A}$$

$$E_{R2} = I_{R2} \times R2 = .5\text{ A} \times 50\text{ ohms} = 25\text{ V}$$

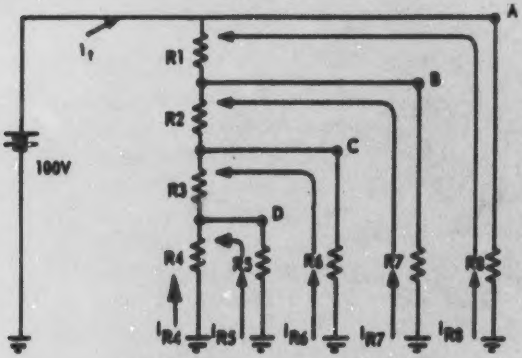


Figure 6-17

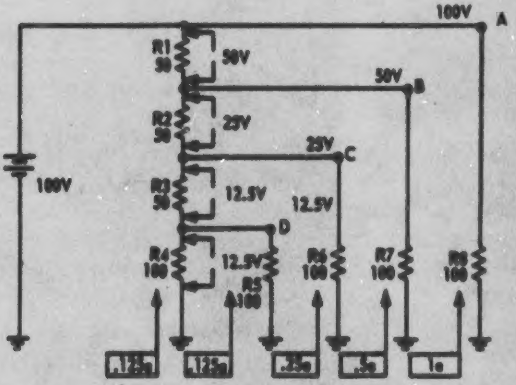


Figure 6-18

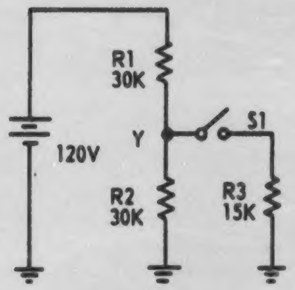


Figure 6-19

$$E_C = E_B - E_{R2} = 50\text{ V} - 25\text{ V} = 25\text{ V}$$

$$I_{R6} = \frac{E_C}{R6} = \frac{25\text{ V}}{100\Omega} = .25\text{ A}$$

Step 4:

$$I_{R3} = I_{R2} - I_{R6} = .5\text{ A} - .25\text{ A} = .25\text{ A}$$

$$E_{R3} = I_{R3} \times R3 = .25\text{ A} \times 50\text{ ohms} = 12.5\text{ V}$$

$$E_D = E_C - E_{R3} = 25\text{ V} - 12.5\text{ V} = 12.5\text{ V}$$

$$I_{R5} = \frac{E_D}{R5} = \frac{12.5\text{ V}}{100\Omega} = .125\text{ A}$$

$$I_{R4} = \frac{E_D}{R4} = \frac{12.5\text{ V}}{100\Omega} = .125\text{ A}$$

$$I_t = I_{R4} + I_{R5} + I_{R6} + I_{R7} + I_{R8}$$

$$= .125\text{ A} + .125\text{ A} + .25\text{ A} + .5\text{ A} + 1\text{ A}$$

$$= 2\text{ A}$$

6-37. Analyze the voltage divider circuit shown in figure 6-19. The load resistor R3 is connected through switch S1 to point Y on the voltage divider. First, calculate the voltage at point Y with the switch open, under a no-load condition. Second, calculate the voltage at point Y under a loaded condition, with the switch closed.

Switch Open:

$$R_t = R1 + R2 = 30\text{k}\Omega + 30\text{k}\Omega = 60\text{k}\Omega.$$

$$I_t = \frac{E_a}{R_t} = \frac{120\text{ V}}{60\text{k}\Omega} = 2\text{ mA}$$

$$E_{R2} = I_{R2} \times R2 = 2\text{ mA} \times 30\text{k ohms} = 60\text{ V}$$

$$E_Y = E_{R2} = 60\text{ V}$$

6-38. The voltage at point Y without the load device connected to the divider is 60 volts. Total resistance of the circuit is 60k ohms and the total current is 2 mA.

Switch Closed:

$$R_e = \frac{R2 \times R3}{R2 + R3} = \frac{30\text{k}\Omega \times 15\text{k}\Omega}{30\text{k}\Omega + 15\text{k}\Omega} = 10\text{k}\Omega$$

$$R_t = R1 + R_e = 30\text{k}\Omega + 10\text{k}\Omega = 40\text{k}\Omega.$$

$$I_t = \frac{E_a}{R_t} = \frac{120\text{ V}}{40\text{k}\Omega} = 3\text{ mA}$$

$$E_{R1} = I_{R1} \times R1 = 3\text{ mA} \times 30\text{k}\Omega = 90\text{ V}$$

$$E_Y = E_a - E_{R1} = 120\text{ V} - 90\text{ V} = 30\text{ V}$$

6-39. The voltage at point Y with the load device connected to the divider is 30 volts. Total resistance of the circuit is 40k ohms and total current is 3 mA. Looking back over the calculations, the following are conclusions concerning a load connected to a voltage divider:

a. Total circuit resistance decreases.

b. Total circuit current increases.

c. The voltage drop across the loaded portion of the divider decreases.

d. Voltage drop across the series resistor increases.

6-40. All voltages obtained in the above explanations have been positive in polarity. In these examples, the negative terminal of the battery was grounded. This makes all other points in the circuit positive with reference to ground.

6-41. Recall that voltage dividers can supply negative voltages when the positive battery terminal is grounded. With the most positive point grounded, all other points in the circuit are negative with reference to that point.

6-42. When you studied unloaded voltage dividers, you learned that both positive and negative voltages may be obtained from a single voltage divider. This happens if some point of the resistive network is grounded. This point could NOT be one of the battery terminals, but must be in the resistive network of the voltage divider. Calculations for these circuits are the same as for the examples shown. Just keep in mind that ground is merely a reference point.

## Chapter 7

# TROUBLESHOOTING DC RESISTIVE CIRCUITS

### 7-1. Troubleshooting Series Resistive Circuits

7-2. What is "troubleshooting"? It is the process of locating causes for circuit failure or troubles. At this time troubleshooting will be limited to DC series resistive circuits that contain opens and shorts.

7-3. Before proceeding, study the definition of an open circuit, a short circuit, and continuity.

OPEN CIRCUIT - A circuit that is not complete or continuous, such as a broken wire or burned out fuse.

SHORT CIRCUIT - A low resistance connection between two points of different potential in a circuit, usually accidental and usually resulting in excessive current flow that may cause damage.

CONTINUITY - A state of being continuous, connected together, a circuit that is not broken or does not have an open.

7-4. Consider some examples of opens. In figure 7-1, the battery shown has a loose connection. A loose connection is the same as no connection, which is the same as an open circuit. Any circuit component with a loose connection opens the circuit, which stops current flow. Another type of trouble that will cause an open is a burned out component.

7-5. Figure 7-2 shows a burned out resistor. When a resistor becomes overheated, one of two things will happen: The resistor value will change or the resistor will completely burn apart due to the excessive current flowing through it.

7-6. Figure 7-3 shows three more likely causes for an open circuit, a burned out lamp bulb, a burned out fuse, and a broken wire. All of these are examples of an open, and they all give the same results.

7-7. The examples of opens, so far, could have been found by visual inspection. However, you will encounter opens in circuits that cannot be seen. In these, you will have to use a meter to locate the open circuit.

7-8. The circuit in figure 7-4 is used to light a lamp. Because of the open resistor, you do not have continuity and the lamp will not light. Suppose the resistor appears to be all right upon visual inspection. How can you tell it is open: You can do this with a voltmeter or an ohmmeter.

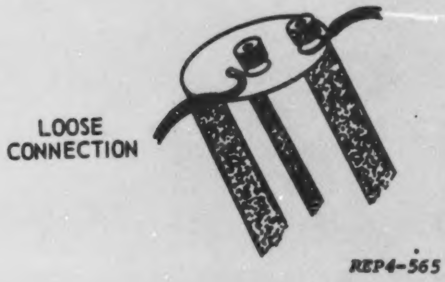


Figure 7-1

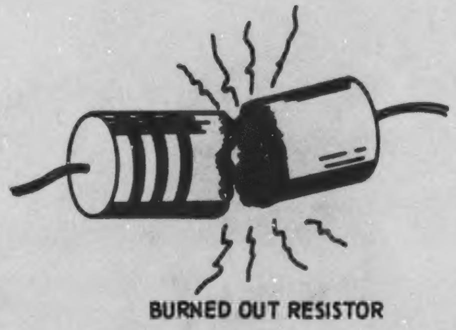


Figure 7-2

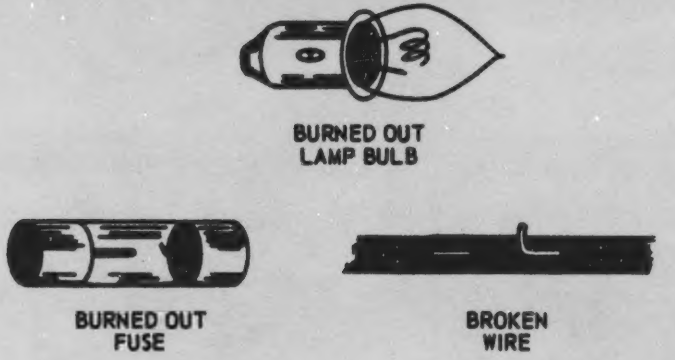
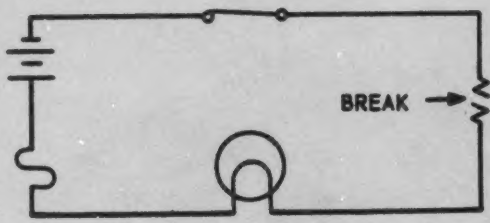


Figure 7-3

REP4-567

7-9. First, connect the voltmeter across the lamp as shown in figure 7-5. A reading of 0 volts will be indicated on the meter. The reason for the zero reading is the open resistor, which will not allow current to flow through the circuit. With no current flowing through the lamp, no voltage will be dropped across the lamp.



REP4-568

Figure 7-4

7-10. So remember this: When you connect a voltmeter across a good component in a series circuit having an open circuit, the reading will be zero.

7-11. Now, connect the voltmeter across the resistor as shown in figure 7-6.

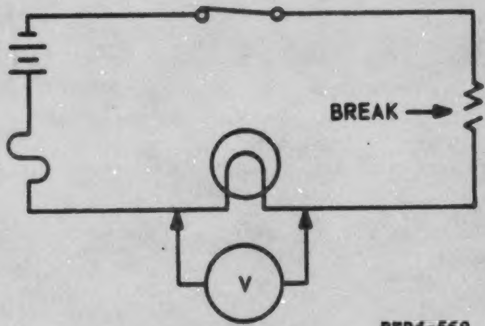


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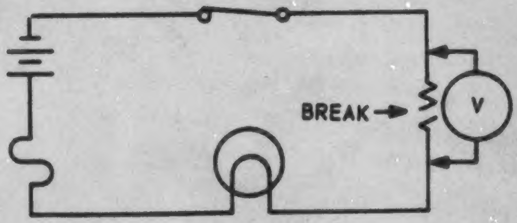
Figure 7-5

7-12. The voltmeter has, in a sense, closed the circuit by paralleling the burned out resistor and provided continuity in the circuit. Current will flow from the negative terminal of the battery, through the switch, through the voltmeter, through the lamp and back to the positive terminal of the battery. This current is too small to light the lamp due to the high resistance of the voltmeter. As a result of its high resistance the voltmeter will read the applied voltage.



REP4-570

Figure 7-6

7-13. So, you have another good point to remember. When the voltmeter is placed across the open component in a series circuit, it will read the applied voltage.

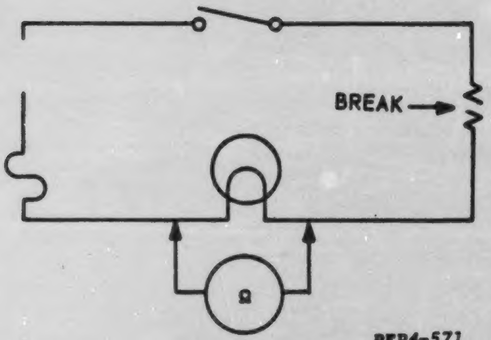


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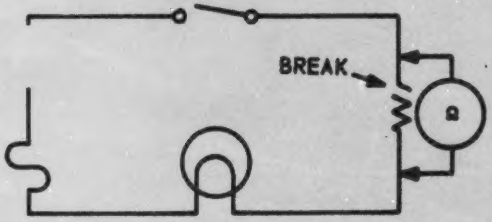
Figure 7-7



REP4-572

Figure 7-8

7-14. An open component can also be found with an ohmmeter. To use the ohmmeter, the applied voltage, or battery, must be disconnected. Notice that the battery in figures 7-7 and 7-8 has been removed. Now connect the ohmmeter across the lamp as shown in figure 7-7.

7-15. With the ohmmeter connected across the lamp, you would read the resistance of the lamp. A good point to remember: When an ohmmeter is connected across a good component, it will indicate the resistance of the component. It also shows continuity.

7-16. With the ohmmeter connected across the resistor as shown in figure 7-8, it will indicate infinite resistance, or an open. So remember, when you connect the ohmmeter across an open component, the ohmmeter will indicate infinite resistance.

7-17. By now you should have a clear understanding of what an open is, and how to find opens in a series DC circuit. Now, study the other common trouble in electrical circuits - the short.

7-18. You have seen how an open stops current flow. Shorts produce just the opposite effect. A short across a series component produces a larger than normal current flow by reducing resistance. Some examples of shorts are shown in figure 7-9. The examples of shorts are two bare wires in a circuit touching each other, connecting the two terminals of a resistor together, connecting two terminals of a battery together, or improper wiring.

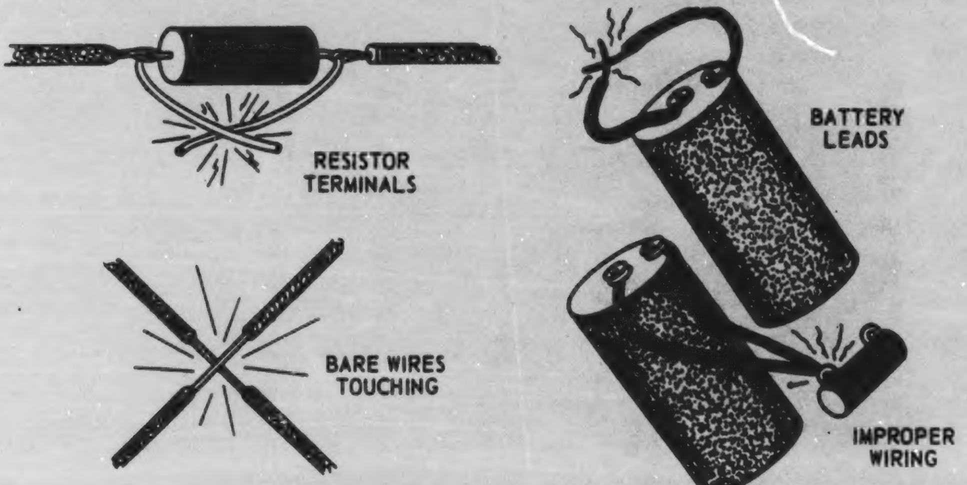


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Figure 7-9

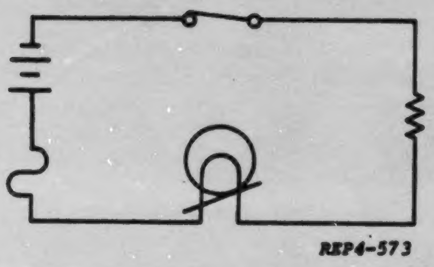


Figure 7-10

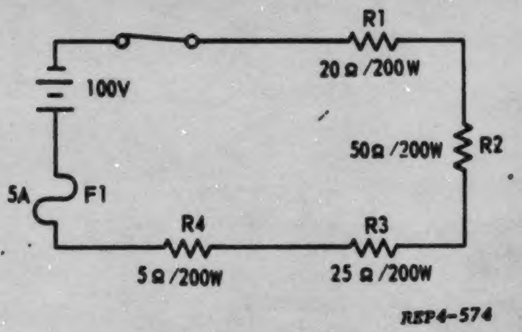


Figure 7-11

7-19. Since you know that a short is a connection of two conductors of a circuit through a very low resistance, consider the circuit shown in figure 7-10. This circuit is designed to light a lamp. Since the resistance of the lamp is normally low, a resistor is connected in series with it to control the amount of current flowing through the lamp. If the lamp is shorted out, total circuit resistance would decrease, and the current would increase. This increase in current would cause the resistor to become hot. If the battery voltage were high enough, the increased current could destroy the resistor. However, since we have a safety device (fuse) in the circuit, the fuse should open before the resistor is damaged. The fuse is designed to open the circuit before the current exceeds the rated values for the other components in the circuit.

7-20. Usually, a short circuit will produce an open circuit by either blowing the fuse or burning out a component. However, in a circuit such as the one in figure 7-11, there may be additional resistors in the circuit which will not allow one shorted resistor to increase the current sufficiently to blow the fuse or burn out a component. Examine the circuit and determine the increase in current that will be caused by a shorted resistor.

7-21. First, consider the circuit without a short.

a. $R_t = R1 + R2 + R3 + R4$

$= 20\Omega + 50\Omega + 25\Omega + 5\Omega$

$= 100$ ohms

b. $I_t = \frac{E_a}{R_t}$

$= \frac{100\text{ V}}{100\Omega}$

$= 1$ amp

7-22. Now see what happens when R2 is shorted.

$R_t = R1 + R3 + R4$

$= 20$ ohms $+ 25$ ohms $+ 5$ ohms

$= 50$ ohms

$I_t = \frac{E_a}{R_t}$

$= \frac{100\text{ V}}{50\Omega}$

$= 2$ amps

7-23. With resistor R2 shorted out, the fuse will not blow since the current does not exceed the rating of the fuse. The current is insufficient to damage any of the remaining resistors. As in the case of the open, use either a voltmeter or ohmmeter to find the short if it is not visually apparent.

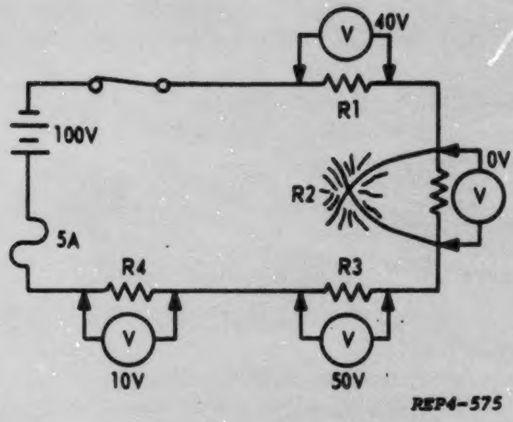


Figure 7-12

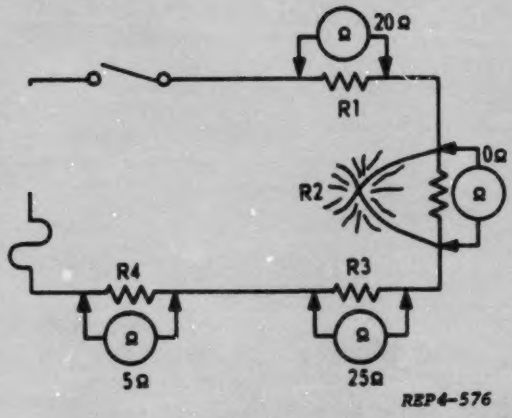


Figure 7-13

7-24. In figure 7-11, suppose resistors R1, R2, and R3 were shorted out. In this case the values would be:

$$R_t = R4$$

$$= 5 \text{ ohms}$$

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{100\,V}{5\,\Omega}$$

$$= 20 \text{ amps}$$

7-25. Now the current has exceeded the rating of the fuse (5 amps). The fuse will blow and result in an open circuit.

7-26. In figure 7-12, a voltmeter is connected across each resistor in the circuit. The reading on the meter connected across resistor R1 indicates 40 volts, across R2 - 0 volts, across R3 - 50 volts, and across R4 - 10 volts. The voltage that would normally have been dropped across R2 has been redistributed among R1, R3 and R4. The rule for finding a short using a voltmeter is:

> When the voltmeter is connected across a good component in a series circuit that contains a short, the meter will indicate a higher than normal voltage (if only two resistors were in the circuit, the meter would read the applied voltage), and when the voltmeter is connected across a shorted component in a series circuit, the meter will read zero.

7-27. To find a short using the ohmmeter, make an intentional open circuit by disconnecting the battery. Take four ohmmeters and connect them as shown in figure 7-13. The location of the short would be obvious.

7-28. In figure 7-13, the ohmmeter connected across resistor R1 is reading 20 ohms, the meter across R2 is reading zero, the meter across R3 is reading 25 ohms, and the meter across R4 is 5 ohms. So the rules for finding a short with the ohmmeter are:

> When the ohmmeter is connected across a good component in a series circuit, the meter will indicate the resistance of the component. When the ohmmeter is connected across a shorted component, it will indicate zero ohms resistance.

7-29. In some cases the resistor will not be shorted, but it has changed value. In this case you will have to compare the color coded value to the value indicated by the ohmmeter.

7-30. When troubleshooting series DC circuits, remember open circuits have no current flow and shorted circuits have too much current flow.

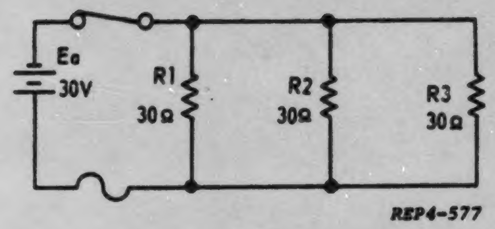


Figure 7-14

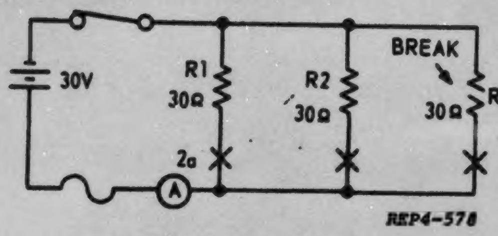


Figure 7-15

### 7-31. Troubleshooting Parallel Resistive Circuits

7-32. Troubleshooting parallel circuits follows the same techniques used in troubleshooting series circuits. That is, use a multimeter to aid in locating a defective component. The only difference in troubleshooting a parallel circuit is in the indications produced by a defective component. For example, an open component in a series circuit gives an indication of no circuit current. This indication is not true with respect to a parallel circuit. An open component in a parallel circuit gives an indication of a decrease in total current.

7-33. Take the parallel circuit shown in figure 7-14 and see what effect an open resistor has on circuit operation. For ease of explanation three resistors of equal size have been used. Assume that resistor R3 is open. Current continues to flow through the good components in a parallel circuit. However, current ceases to flow through the open component. An open component in this type of circuit cannot be detected with a voltmeter. A quick way to detect an open component or resistor in this case is to use an ammeter or ohmmeter. Before going any further calculate current through R1.

$$I_{R1} = \frac{E_a}{30\Omega}$$

$$= \frac{30\,V}{30\Omega}$$

$$= 1\,A$$

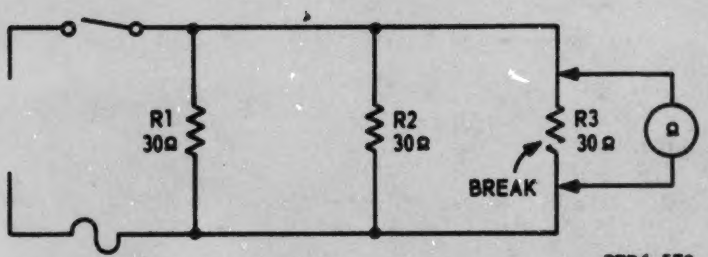
7-34. Since all resistors in this circuit are of equal size and the current flow through R1 is known then, by Ohm's and Kirchhoff's Laws, the current flow through R2 must be 1 amp and the current flow through R3 will also equal 1 amp. Total current flow equals the sum of the branch currents.

$$I_t = 1\,A + 1\,A + 1\,A$$

$$= 3\,A$$

Since the total current and branch currents are known, insert an ammeter into the circuit as shown in figure 7-15. At this point in the circuit, the ammeter should read the total current, 3 amps. However, as indicated in the diagram, the meter reads 2 amps. Since the branch current is equal to 1 amp in each branch, then one branch must be open. If the ammeter is inserted into each branch at point X, the current through R1 would indicate 1 amp, through R2 would indicate 1 amp, and through R3 would indicate 0 amps.

7-35. So now we can say: When a parallel circuit contains an open branch, no current flows in that branch and the total current of the circuit decreases. The reason the total current decreases is because the total resistance (an open would be the same as removing R3) has increased. When troubleshooting a parallel circuit with an ammeter, the open resistor will be located by a reading of zero current in that branch.



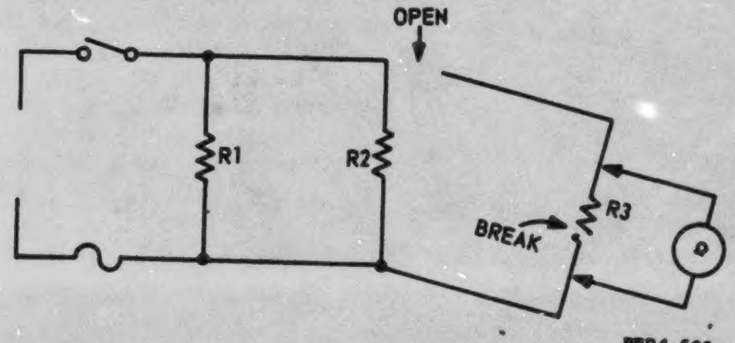
REP4-579

Figure 7-16

7-36. Another way to locate this same trouble is with the use of an ohmmeter. If an ohmmeter were connected across R3, as shown in figure 7-16, a reading of continuity would be obtained. This is because R3 is in parallel with R1 and R2. Although R3 is open, the ohmmeter will still measure the resistance of R1 and R2 in parallel. Two 30-ohm resistors in parallel would give us an equivalent resistance of 15 ohms ($R_t$ = R/N). Note that the battery is disconnected when the ohmmeter is used.

7-37. To accurately determine the condition of R3 with the use of an ohmmeter, intentionally open the circuit as shown in figure 7-17. In this manner the resistor being checked, R3, is not shunted or paralleled by R1 and R2. If R3 is open; the ohmmeter would indicate an infinite resistance. In other words, to check the resistance of a resistor in a parallel circuit, one end of the resistor must be disconnected from the circuit.

7-38. In a series circuit, you learned that a voltmeter is often used as an aid in locating a defective component such as an open resistor. You also learned that a voltmeter reads the applied voltage when it is placed across an open circuit. This technique cannot be followed in troubleshooting a simple parallel circuit. Refer back to figure 7-15. Resistor R3 is open. If you placed a voltmeter across R3, it would read the applied voltage, 30 V. If you placed a voltmeter across R1 and R2, it would also read the applied voltage. Remember, in a parallel circuit, there is only one voltage, which is the applied voltage. When a voltmeter is placed across a good component or an open component in a simple parallel circuit, the voltmeter still reads the applied voltage. It follows then in troubleshooting a parallel circuit that you should rely upon the use of an ammeter or ohmmeter to locate a defective component.



REP4-580

Figure 7-17

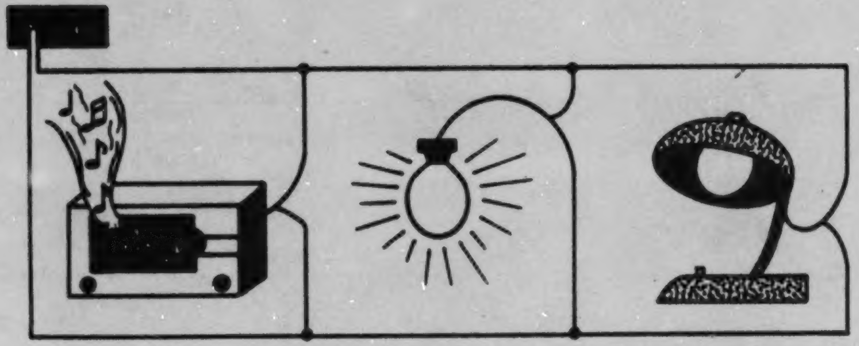


Figure 7-18

7-39. In one way or another you have always applied troubleshooting techniques to your everyday living. Take, for example, the parallel circuit shown in figure 7-18. Suppose, when you operate the switches, the radio and overhead lamp work; but your desk lamp failed to light. Because the radio and overhead lamp work, you immediately assume voltage is being applied to the circuit. You would now probably check the bulb, cord, and switch, in that order, to determine what specific component part of the lamp was defective. This example simply illustrates the point that when a parallel circuit contains an open branch, the remaining branches continue to function.

7-40. Thus far, troubleshooting parallel circuits has dealt with open components. Now see what effect a shorted component has on a parallel circuit. Refer to figure 7-19. Assume R3 is shorted. This condition would present a current path with negligible resistance. Current would increase to an excessive value through the short.

7-41. Another way to look at the circuit with R3 shorted is just like connecting the two terminals of the battery together. In either case, current rises to an excessive value and the fuse would burn out. Once the fuse has blown, the circuit also has an open condition.

7-42. Since the indication of a shorted component is usually a blown fuse, troubleshooting with an ammeter or voltmeter becomes difficult. However, you still have the ohmmeter as an aid in locating the defective component. As in the case of troubleshooting for an open resistor in a parallel circuit, a shorted resistor can be detected with an ohmmeter only if one end is disconnected as illustrated in figure 7-17. A shorted resistor will give a reading of 0 ohms on the ohmmeter.

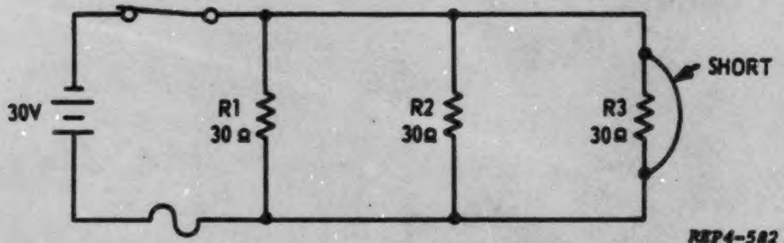


Figure 7-19

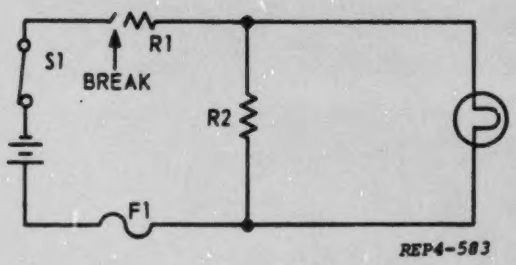


Figure 7-20

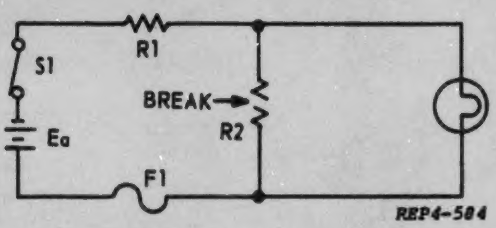


Figure 7-21

### 7-43. Troubleshooting Series-Parallel Circuits

7-44. Troubleshooting a series-parallel resistive circuit is similar to troubleshooting a series or a parallel resistive circuit. Two troubles you will encounter in a series-parallel circuit are our old enemies - the open and the short. First, see what effect an open has on a series-parallel circuit. Refer to figure 7-20. Note that an open has occurred in the series portion of the circuit.

7-45. When an open occurs anywhere in the series portion of a series-parallel circuit, current flow in the entire circuit will stop. In this case the circuit will cease to function and the lamp will not light. If an open occurs in the parallel portion of a series-parallel circuit, the remaining portion of the circuit will continue to function. Refer to figure 7-21. In this case the lamp will continue to burn, but brighter. Analyzing the circuit indicates that with R2 open, the circuit becomes a simple series circuit. Also, with R2 out of the circuit, total resistance increases and total current decreases. A decrease in total current results in a decrease in voltage drop across R1. If the voltage drop across R1 decreases, then, by Kirchhoff's Law the voltage drop across the lamp must increase. This increase in voltage across the lamp will cause current through the lamp to increase and the lamp will glow brighter. If current through the lamp is excessive, the lamp will burn out and all current flow will cease.

7-46. If an open occurs in the branch containing the lamp, as shown in figure 7-22, the lamp will fail to glow, but current through the series portion of the circuit will continue to flow. This time the increase in voltage will be felt across R2.

7-47. Another approach to troubleshooting a series-parallel circuit is with the use of a voltmeter or ohmmeter. Refer to the circuit diagram in figure 7-23.

7-48. Troubleshooting series-parallel circuits with a voltmeter can be easy, if component sizes and the applied voltage are known. With a little mathematical computation, troubleshooting can be done with accuracy.

7-49. To theoretically troubleshoot the circuit in figure 7-23, you must make certain assumptions. The first assumption is that all components are good, except the one being checked.

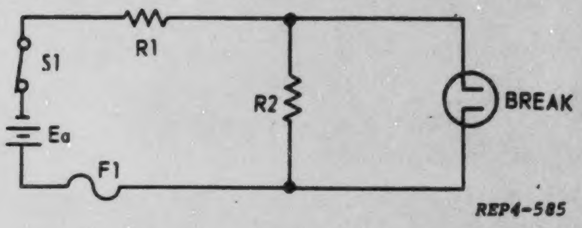


Figure 7-22

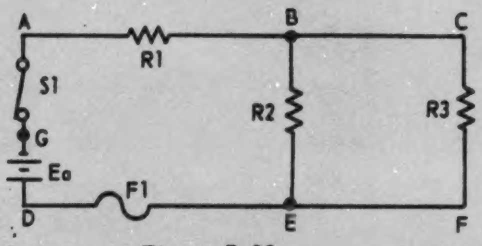


Figure 7-23

| COMPONENT | OPENED | SHORTED | GOOD |
|---|---|---|---|
| SWITCH | APPLIED VOLTAGE | 0V | WHEN CLOSED -0V<br>WHEN OPEN - $E_a$ |
| FUSE | APPLIED VOLTAGE | 0V | SMALL VOLTAGE |
| R1 | APPLIED VOLTAGE | 0V | A PORTION OF THE APPLIED VOLTAGE |
| R2 | VOLTAGE WILL INCREASE | 0V | A PORTION OF THE APPLIED VOLTAGE |
| R3 | VOLTAGE WILL INCREASE | 0V | A PORTION OF THE APPLIED VOLTAGE |

REP4-587

Chart 7-1

7-50. Chart 7-1 gives the indications which can be expected when the voltmeter is placed across each component.

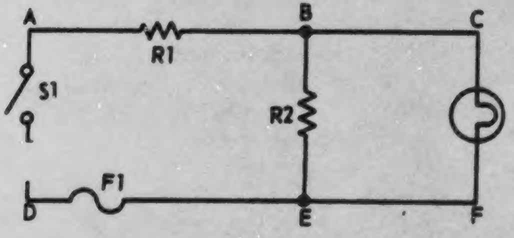
7-51. Troubleshooting with an ohmmeter can be accomplished in a similar manner. Remember, whenever troubleshooting with an ohmmeter, the power must first be removed from the circuit. Power has been removed in figure 7-24 by opening S1. Begin by checking the series portion of the circuit. By placing the meter between points A and B, the resistance of R1 can be checked. If resistor R1 is open, a reading of infinite resistance will be obtained on the meter. If R1 is good, its value on the meter will be the color coded value.

7-52. Connecting the meter between points D and E will check the fuse. If the fuse is open, a reading of infinite resistance will be obtained on the meter. If the fuse is good, a reading of near zero resistance will be obtained.

7-53. Like the voltmeter, the ohmmeter can give misleading indications in the parallel portion of the circuit. In order to check the circuit between points B and E, one of these points will have to be broken (disconnected) as in figure 7-25.

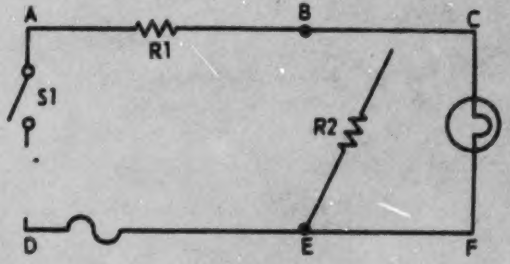
7-54. With the top resistor R2 disconnected, a meter placed between points B and E would check the circuit from B to C, C to F, and F to E.

7-55. Troubleshooting R2 shoud present no problem. Simply connect the ohmmeter across R2. An open resistor would be indicated by an infinite reading.



REP4-588

Figure 7-24



REP4-589

Figure 7-25

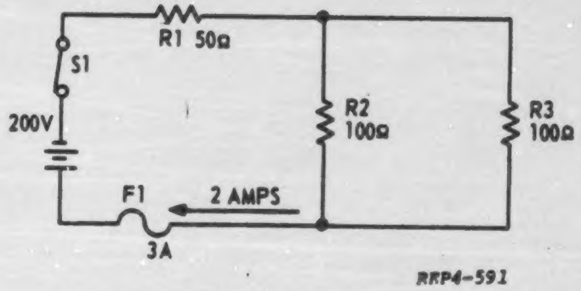


Figure 7-26

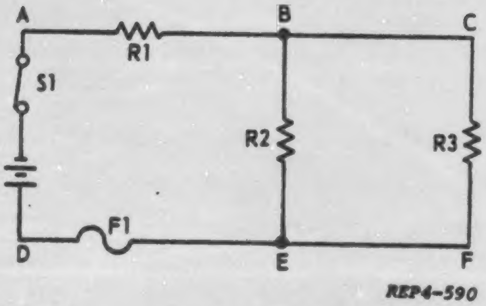


Figure 7-27

7-56. Now see how a short affects a series-parallel circuit. A short in the series portion of a series-parallel circuit will cause a decrease in total resistance. This, in turn, will cause the total current to increase. Examine the circuit as shown in figure 7-26.

7-57. Since R1 is 50 ohms and the equivalent resistance of R2 and R3 is 50 ohms, the total resistance is 100 ohms. The total current is 2 amps. If R1 becomes shorted, the total resistance would decrease to 50 ohms and the total current would increase to 4 amps. This increase in current would be sufficient to blow the 3-amp fuse. The same thing would occur in the circuit if either R2 or R3 became shorted. The total resistance in the circuit would be 50 ohms, the value of the series resistor only.

7-58. From your study you should conclude that any time a short occurs in a series-parallel circuit, the total resistance will decrease and the total current will increase. A short will often produce an open circuit by either blowing the fuse or burning out a circuit component.

7-59. Like an open, a short can be detected with either a voltmeter or an ohmmeter. Examine the circuit shown in figure 7-27.

7-60. Placing the voltmeter across points B and E would indicate the condition of R1 and F1. If R1 is shorted, the applied voltage would be indicated between these points. If R1 is good, the voltage indicated would be less than the applied voltage.

7-61. An indication of a short in the parallel portion of the circuit may be obtained with a voltmeter, but the particular defective branch cannot be determined. By connecting the voltmeter across points B and E, the parallel combination can be checked. If one of the resistors in the parallel combination is shorted, the voltage reading between points B and E will be zero. It is assumed that F1 is good. To determine which resistor is shorted, either R2 or R3 will have to be disconnected from the circuit and checked individually.

7-62. Troubleshooting for a short with the ohmmeter is an identical process of that of troubleshooting for an open. The only difference will be in the reading obtained on the meter. When the ohmmeter is connected across a shorted component, a reading of zero will be indicated. Remember to always remove the power source from the circuit before using the ohmmeter.

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PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 2

## SAFETY AND FIRST AID

1 May 1974

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 5-1258

DO NOT USE ON THE JOB

Basic and Applied Flectronics Dept
Keesler Air Force Base, Mississippi

ATC GUIDANCE PACKAGE 3AQR3X020-X
KEP-GP-2
1 May 1974

# ELECTRONICPRINCIPLES (MODULAR SELF-PACED)

## MODULE 2

## SAFETY AND FIRST AID

This guidance package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

| | Page |
|---|---|
| Overview | 1 |
| List of Resources | 2 |
| Digest | 3 |
| Adjunct Guide | 4 |
| Module Self-Check | 11 |
| Critique | 13 |

Supersedes KEP-GP-2, 1 October 1973. Existing stock will be used first.

OVERVIEW

## SAFETY AND FIRST AID

1. SCOPE: Safety is the responsibility of every individual in the Air Force. This includes personal safety and the safety of others. Common causes of accidents are identified and safety precautions to be used near electrical equipment are discussed. Treatment of shock victims is explained as well as the procedure for controlling fire.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a group of statements, select those that describe safety precautions whch should be observed when working on electrical equipment.

b. From a group of statements, select those which name the proper first aid measure to be used for the treatment of electrical shock.

c. From a list of fire extinguisher types, select the one used for electrical fires.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

## SAFETY AND FIRST AID

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

AUDIO-VISUALS

Television Lesson, Safety, TVK 30-101B

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

DIGEST

# SAFETY AND FIRST AID

## CAUSES OF ACCIDENTS

Accidents are expensive. The result of accidents is the loss, damage, or destruction of equipment, as well as injury and death to personnel. Accidents can be prevented by eliminating their causes. Some of the common causes of accidents are:

1. Carelessness
2. Horseplay
3. Lack of experience
4. Failure to follow instructions
5. Failure to observe proper safety precautions
6. Improper use of tools and equipment.

## PRECAUTIONS

The possibility of electrical shock is the greatest hazard associated with electronic equipment. Some of the precautions to always observe while working on electronic equipment are:

1. Remove jewelry.
2. Keep one hand in your pocket.
3. Have a safety observer.
4. Avoid contact with energized components.
5. Don't experiment.

## ELECTRICAL SHOCK TREATMENT

In the event of an accident and the body comes in contact with an energized component, the electric shock may be severe enough to interrupt normal body functions and cause respiratory system or heart failure. The proper first aid treatment for severe electric shock is the immediate restoration of the victim's heartbeat and breathing. The use of closed chest heart massage is recommended for the restoration of the heartbeat and mouth to mouth resuscitation is recommended for the restoration of breathing.

## ELECTRICAL FIRES

Electrical fires are a result of equipment failure or misuse. The use of a water type extinguisher on an electrical fire is not feasible because the water would place the operator in contact with the electrical components. A dry chemical such as carbon dioxide must be used to displace the oxygen near the fire to extinguish the blaze.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ADJUNCT GUIDE

## SAFETY AND FIRST AID

INSTRUCTIONS:

Study the reference material as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to Student Text Volume I and read paragraphs 1-1 through 1-7. Return to this page and answer the following questions.

1. List the two major causes of accidents.

a. ______________________________

b. ______________________________

2. Human characteristics that cause human errors include:

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

B. Turn to Student Handout, Safety Precautions and First Aid for Electronic Environment, KEP 112, and read SAFETY on page 1. Return to this page and answer the following questions.

1. List five causes of accidents.

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

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2. It is your responsibility to ______________ and ______________ unsafe conditions which cause accidents.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

C. Turn to Student Text Volume I and read paragraphs 1-8 through 1-24. Return to this page and answer the following questions.

1. The dangers of electricity can be avoided by the use of:

a. ______________________________

b. ______________________________

c. ______________________________

2. List eight precautions to observe while working on electronic equipment.

a. ______________ e. ______________

b. ______________ f. ______________

c. ______________ g. ______________

d. ______________ h. ______________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

D. Turn to Student Text Volume I and read paragraphs 1-25 through 1-37. Return to this page and answer the following questions.

1. When someone comes in contact with a HOT wire, you should:

___ a. Call for medical assistance.

___ b. Start artificial respiration immediately.

___ c. Remove the victim from the electrical source.

___ d. Clear the air passage.

2. The best method of artificial respiration is the:

___ a. Prone pressure method.

___ b. Back pressure, arm lift method.

___ c. Back pressure, hip lift method.

___ d. Mouth to mouth resuscitation method.

Continue to bottom of next page for next question.

## ADJUNCT GUIDE

**ANSWERS TO A.**

1a. human error.
b. material failure.

2a. inattentiveness.
b. excitability.
c. impatience.
d. carelessness.
e. ignorance.

If you missed ANY questions, review the material before you continue. If not, proceed to item B.

**ANSWERS TO B.**

1a. NOT following safety precautions.
b. NOT using safety devices.
c. Horseplay.
d. Operating equipment without authority or experience.
e. carelessness.

2. identify, eliminate.

If you missed ANY questions, review the material before you continue. If not, proceed to item C.

**ANSWERS TO C.**

1a. Common sense.
b. Safety precautions.
c. Knowledge.

2a. Turn equipment Off.
b. Never depend on a fuse to protect human life.
c. Keep hands free of extra tools.
d. Be a one-armed technician.
e. Don't experiment.
f. Don't wear jewelry, rings, watches, bracelets, etc.
g. Keep dry.
h. Check equipment grounds.

If you missed ANY questions, review the material before you continue. If not, proceed to item D.

---

3. Artificial respiration should be continued until

____ a. a doctor arrives.

____ b. the eyes dilate.

____ c. color returns to the skin.

____ d. victim starts breathing.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

E. Turn to Student Handout, Safety Precautions and First Aid for Electronic Environments, KEP 112, and read page 14. Return to this page and answer the following questions.

1. Cardiac arrest closed heart massage requires the efforts of

___ a. one person.

___ b. two persons.

___ c. three persons.

___ d. four persons.

2. Using the closed heart massage procedure, the

___ a. chest is compressed 3 cm to 5 cm and held for 1/2 second, 60 to 80 times per minute.

___ b. chest is compressed 1/2 cm and held for 3 to 5 seconds, 12 to 20 times per minute.

___ c. chest is expanded 12 to 20 times per minute.

___ d. chest is expanded 3 cm to 5 cm, 60 to 80 times per minute.

3. The victim's eyes will dilate when

___ a. blood circulation is adequate.

___ b. air circulation is adequate.

___ c. blood circulation is inadequate.

___ d. air circulation is inadequate.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

F. Turn to Student Text Volume I and read paragraphs 1-54 through 1-58. Return to this page and answer the following questions.

1. Class A fires are usually

___ a. oil or solvents.

___ b. electrical.

___ c. wood or paper.

___ d. gasoline.

**ADJUNCT GUIDE**

**ANSWERS TO D.**

1. c 2. d 3. d

If you missed ANY questions, review the material before you continue. If not, proceed to item E.

**ANSWERS TO E.**

1. b 2. a 3. c

If you missed ANY questions, review the material before you continue. If not, proceed to item F.

---

2. Class B fires are best extinguished using

____ a. water.

____ b. soda acid.

____ c. $CO_2$.

____ d. calcium chloride.

3. Class C fires present an additional hazard of

____ a. explosion.

____ b. toxic vapors.

____ c. electrical shock.

____ d. smoke inhalation.

4. Electrical fires require the use of a Class ____ extinguisher.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

# NOTES

ADJUNCT GUIDE

ANSWERS TO F.

1. c
2. c
3. c
4. c

If you missed ANY questions, review the material before you continue. If not, proceed to next page.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## SAFETY AND FIRST AID

QUESTIONS:

1. List five safety precautions which should be observed while working on electrical equipment.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

2. A shock victim's breathing may be restored by ______________________________

3. A shock victim's heart beat may be restored by ______________________________

4. To extinguish an electrical fire, you should use ______________________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

## MODULE SELF-CHECK

### ANSWERS TO MODULE SELF-CHECK.

1a. Avoid contact with energized components.
 b. Remove jewelery.
 c. Keep one hand in your pocket.
 d. Have a safety observer.
 e. Don't experiment.

2. Mouth to mouth resuscitation.
3. Closed chest heart massage.
4. A dry chemical ($CO_2$).

**HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.**

ATC GP 3AQR3X020-X
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KEP-GP-3

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 3

## ELECTRONIC MATHEMATICS

1 May 1974

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-3
1 May 1974

# ELECTRONIC PRINCIPLES

## MODULE 3

## ELECTRONIC MATHEMATICS

This Guidance Package is designed to guide you through this module of the Electronic Principles course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

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Module Self-Check 21

Supersedes KEP-GP-3, 1 November 1973. Use old edition until exhausted.

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## ELECTRONIC MATHEMATICS

1. SCOPE: This module discusses powers of 10 and how to convert any number to standard powers of 10 notation. Computation using powers of 10 is fully covered along with the use of standard prefixes.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

   a. Given five multiplication and five division problems, solve by using powers of 10.

   b. Given five electronic equations, solve at least four correctly for any unknown value.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

## LIST OF RESOURCES

## ELECTRONIC MATHEMATICS

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

### READING MATERIALS

Digest

Adjunct Guide with Student Text

### AUDIO-VISUAL

Television Lesson, Powers of Ten, TVK 30-153

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

# ELECTRONIC MATHEMATICS

## POWERS OF TEN

The technique of using powers of 10 can greatly simplify mathematical calculations. In the powers of 10 system, a very large or very small number is expressed as a quantity between one and 10 and the appropriate positive or negative power of 10. The value and sign of the exponent are determined by the number of places and the direction the decimal point is moved.

**Examples:**

$$3{,}000{,}000 = 3 \times 10^{6}$$

$$51{,}000 = 5.1 \times 10^{4}$$

$$0.005 = 5 \times 10^{-3}$$

$$0.00000047 = 4.7 \times 10^{-7}$$

Study the information in figure 1.

| NUMBER | POWER OF TEN | PREFIX | SYMBOL |
|---|---|---|---|
| 1 000 000 000 000 | $10^{12}$ | tera | T |
| 1 000 000 000 | $10^{9}$ | giga | G |
| 1 000 000 | $10^{6}$ | mega | M |
| 1 000 | $10^{3}$ | kilo | k |
| 100 | $10^{2}$ | hecto | h |
| 10 | $10^{1}$ | deka | da |
| 0.1 | $10^{-1}$ | deci | d |
| 0.01 | $10^{-2}$ | centi | c |
| 0.001 | $10^{-3}$ | milli | m |
| 0.000 001 | $10^{-6}$ | micro | μ |
| 0.000 000 001 | $10^{-9}$ | nano | n |
| 0.000 000 000 001 | $10^{-12}$ | pico | p |

Figure 1

Prefixes and symbols are also used to express very large or very small numbers.

## DIGEST

Examples:

1,000,000 units = 1 megaunit

20,000 units = 20 kilounits

0.004 units = 4 milliunits

0.0000056 units = 5.6 microunits

Exponents are handled according to the following rules:

When multiplying numbers, add the exponents.

When dividing numbers, subtract the exponent in the denominator from the exponent in the numerator.

When squaring a number, double the exponent.

When obtaining a square root, halve the exponent.

Examples:

$$1{,}000{,}000 \times 1{,}000 = 1 \times 10^{6} \times 1 \times 10^{3}$$

$$= 1 \times 10^{9}$$

$$47{,}000 \times 0.056 = (4.7 \times 10^{4}) \times (5.6 \times 10^{-2})$$

$$= 26.32 \times 10^{2}$$

$$= 2.632 \times 10^{3}$$

$$\frac{50{,}000}{2{,}500} = \frac{5 \times 10^{4}}{2.5 \times 10^{3}}$$

$$= 2 \times 10^{1}$$

$$\frac{0.0075}{0.15} = \frac{7.5 \times 10^{-3}}{1.5 \times 10^{-1}}$$

$$= 5 \times 10^{-2}$$

## EQUATIONS

An equation is a mathematical statement that two quantities are equal. The following axioms can be applied to any equation without changing the equality:

1. Adding the SAME number to BOTH sides.
2. Subtracting the SAME number from BOTH sides.
3. Multiplying BOTH sides by the SAME number.
4. Dividing BOTH sides by the SAME number.
5. Terms equal to a third term are equal to each other.
6. Raising BOTH sides to the SAME power.
7. Taking the SAME root of BOTH sides.

Frequently formulas must be rearranged to find a quantity in terms of the other quantities involved.

Examples:

| | |
|---|---|
| $I = \frac{E}{R}$ | Solve for R. |
| $R \times I = \frac{E}{R} \times R$ | Multiply by R. |
| $RI = E$ | Simplify. |
| $\frac{RI}{I} = \frac{E}{I}$ | Divide by I. |
| $R = \frac{E}{I}$ | Simplify. |
| $X_C = \frac{1}{2\pi fC}$ | Solve for f. |
| $f \times X_C = \frac{1}{2\pi fC} \times f$ | Multiply by f. |
| $\frac{f \times X_C}{X_C} = \frac{1}{2\pi CX_C}$ | Divide by $X_C$. |
| $f = \frac{1}{2\pi CX_C}$ | Simplify. |

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

**ADJUNCT GUIDE**

## ELECTRONIC MATHEMATICS

**INSTRUCTIONS**

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to student text volume 1 and read paragraphs 2-1 through 2-8. Return to this page and answer the following questions.

1. Add these signed numbers:

a. 5 + 3 = ____________

b. -11 + 3 = ____________

c. -4 +(-11)= ____________

d. -543 + 43 = ____________

e. -39 +(-11)= ____________

f. 1000 + 111 = ____________

g. 50 +(-13)= ____________

h. 13 +(-14)= ____________

2. Subtract these signed numbers:

a. 6 - 5 = ____________

b. 6 - 7 = ____________

c. -8 - 4 = ____________

d. 5 -(-5)= ____________

e. 80 -(-5)= ____________

f. -32 -(-2)= ____________

3. Multiply these signed numbers:

a. 3 x 6 = ____________

b. -4 x -5 = ____________

c. 5 x -12 = ____________

d. -39 x -2 = ____________

e. -17 x 3 = ____________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

B. Turn to student text volume 1 and read paragraphs 2-9 through 2-21. Return to this page and answer the following questions.

1. A base number is:

___ a. arrived at through conversion to a power of 10.

___ b. referred to as the power.

___ c. more easily manipulated if it is between 1 and 10.

___ d. none of the above.

2. Enter the proper numerical equivalent for each power of 10 value.

a. $10^6$ = ____________________

b. $10^3$ = ____________________

c. $10^0$ = ____________________

d. $10^{-3}$ = ____________________

e. $10^{-6}$ = ____________________

f. $10^{-12}$ = ____________________

3. Which of the following is a valid advantage of using powers of 10?

___ a. All numbers may evenly divided or multiplied by 10.

___ b. Calculations involving large numbers are simplified.

___ c. More accurate results are produced.

___ d. It is easier to place the decimal point correctly.

4. The number 79,681 is equivalent to:

___ a. $7.9681 \times 10^3$.

___ b. $79.681 \times 10^4$.

___ c. $7.9681 \times 10^5$.

___ d. $7.9681 \times 10^4$.

5. The number 8.632 is equivalent to:

___ a. $8.632 \times 10^1$.

___ b. $86.32 \times 10^2$.

___ c. $8.632 \times 10^0$.

___ d. None of the above.

**ANSWERS TO A:**

1a. 8 b. -8 c. -15 d. -500 e. -50 f. 1,111 g. 37 h. -1

2a. 1 b. -1 c. -12 d. 10 e. 85 f. -30

3a. 18 b. 20 c. -60 d. 78 e. -51

If you missed ANY questions, review the material before you continue.

6. The number 0.00426 is equivalent to:

___ a. $4.26 \times 10^{3}$.

___ b. $4.26 \times 10^{-4}$.

___ c. $.426 \times 10^{-3}$.

___ d. $4.26 \times 10^{-3}$.

7. Convert the following numbers to powers of 10.

a. 2,000 = ___

b. 4,698 = ___

c. 158.342 = ___

d. 7,000,000 = ___

e. 696,000 = ___

f. 18,000 = ___

g. 313,000,000,000 = ___

h. 0.018 = ___

i. 0.00046 = ___

j. 0.1791 = ___

k. 0.000 000 82 = ___

l. 0.9 = ___

m. 0.000 000 000 096 = ___

n. 0.0004 = ___

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

C. Turn to student text volume 1 and read paragraphs 2-22 through 2-25. Return to this page and answer the following questions.

1. Which of the following operations is INCORRECT in the process of multiplying two very large numbers expressed in powers of 10?

__ a. Convert the numbers to be multiplied into powers of 10.

__ b. Combine the exponents through multiplication.

__ c. Combine the numerical coefficients through multiplication.

__ d. Combine the exponents through addition.

2. The product exponent of a multiplication problem expressed in powers of 10 having both positive and negative exponents, will be:

__ a. positive

__ b. negative

__ c. that of the smaller

__ d. that of the larger

3. When working a multiplication problem expressed in powers of 10 and all of the exponents are negative, the exponent in the answer will be:

__ a. positive.

__ b. negative.

__ c. the difference between the negative exponents.

__ d. None of the above.

4. Multiply the following. Express the answers in powers of 10.

a. 716,000 x 1,820,000 = ________________

b. 2,700,000 x 3.1 x $10^4$ = ________________

c. 5.6 x $10^5$ x 3.6 x $10^3$ = ________________

d. .00023 x .0000018 = ________________

e. 6.7 x $10^{-3}$ x 2.8 x $10^{-5}$ = ________________

f. .000021 x 39,000 = ________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

**ANSWERS TO B:**

1. d

2a. 1,000,000 b. 1,000 c. 1 d. 0.001 e. 0.000,001 f. 0.000,000,000,001

3. b 4. d 5. c 6. d

7a. $2 \times 10^3$ b. $4.698 \times 10^3$ c. $1.58342 \times 10^2$ d. $7 \times 10^6$ e. $6.96 \times 10^5$

f. $1.8 \times 10^4$ g. $3.13 \times 10^{11}$ h. $1.8 \times 10^{-2}$ i. $4.6 \times 10^{-4}$ j. $1.791 \times 10^{-1}$

k. $8.2 \times 10^{-7}$ l. $9 \times 10^{-1}$ m. $9.6 \times 10^{-11}$ n. $4 \times 10^{-4}$

If you missed ANY questions, review the material before you continue.

**ANSWERS TO C:**

1. b 2. d 3. b

4a. $1.30312 \times 10^{12}$ b. $8.37 \times 10^{10}$ c. $2.016 \times 10^9$ d. $4.14 \times 10^{-10}$ e. $1.876 \times 10^{-7}$

f. $8.19 \times 10^{-1}$

If you missed ANY questions, review the material before you continue.

D. Turn to student text volume 1 and read paragraphs 2-26 through 2-29. Return to this page and answer the following questions.

1. Division in powers of 10 is:

___ a. the multiplication of base numbers.

___ b. a matter of subtracting exponents.

___ c. easy if you change the sign of the numerator.

___ d. multiplication of exponents.

2. If the denominator in a division problem expressed in powers of 10 has a positive exponent, the:

___ a. numerator is positive.

___ b. exponent will remain positive when it is removed to the numerator.

___ c. exponent is subtracted from the exponent in the numerator.

___ d. numerator is negative.

3. If the numerator has a positive exponent and the denominator has a negative exponent in a division problem in powers of 10:

___ a. the answer will have a negative exponent.

___ b. the answer will have a positive exponent.

___ c. the answer may have a positive or negative exponent.

4. Divide the following. Express the answers in powers of 10.

a. $\frac{21{,}000}{30} =$ ____________________

b. $\frac{176{,}000}{88} =$ ____________________

c. $\frac{180{,}000{,}000}{.0003} =$ ____________________

d. $\frac{42{,}000{,}000}{6{,}000} =$ ____________________

e. $\frac{0.0018}{0.0009} =$ ____________________

f. $\frac{6{,}000{,}000}{200} =$ ____________________

g. $\frac{.000{,}001{,}6}{4{,}000} =$ ____________________

h. $\frac{.03}{3{,}000{,}000} =$ ____________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

E. Turn to student text volume 1 and read paragraphs 2-30 through 2-34. Return to this page and answer the following questions.

1. A basic rule for addition or subtraction of numbers expressed as powers of 10 is that you can only combine numbers having like ____________________

2. Perform the following addition:

a. $(90 \times 10^4) + (40 \times 10^3) =$ ____________________

b. $(4 \times 10^2 + (3 \times 10^5) =$ ____________________

c. $(40 \times 10^1) + (3 \times 10^1) =$ ____________________

d. $(3.6 \times 10^1) + (5.6 \times 10^{-1}) =$ ____________________

ADJUNCT GUIDE

**ANSWERS TO D:**

1. b 2. c 3. b

4a. $7 \times 10^{2}$ b. $2 \times 10^{3}$ c. $6 \times 10^{11}$ d. $7 \times 10^{3}$ e. $2 \times 10^{0}$

f. $3 \times 10^{4}$ g. $4 \times 10^{-10}$ h. $3.33 \times 10^{-9}$

If you missed ANY questions, review the material before you continue.

3. Perform the following subtractions:

   a. $(4 \times 10^{-6}) - (2 \times 10^{-12}) =$ ____________________

   b. $(7.8 \times 10^{6}) - (96 \times 10^{4}) =$ ____________________

   c. $(5 \times 10^{0}) - (7 \times 10^{1}) =$ ____________________

   d. $(13 \times 10^{-1}) - (6 \times 10^{-2}) =$ ____________________

4. Solve the following problems:

   a. $1.465 + 25 - 3.2 =$ ____________________

   b. $306 - (3 \times 10^{-2}) =$ ____________________

   c. $(44 \times 10^{0}) - (3.8 \times 10^{0}) + (56 \times 10^{2}) =$ ____________________

5. To square a number containing a power of 10, square the ________________ and multiply the ________________ by 2.

6. To take the square root of a number containing a power of 10, first insure that the exponent of 10 is ______________ .

7. Complete the following problems:

   a. $(1 \times 10^{0})^{2} =$ ____________________

   b. $(2 \times 10^{3})^{2} =$ ____________________

   c. $(5 \times 10^{5})^{2} =$ ____________________

   d. $(.0004)^{2} =$ ____________________

8. Complete the following problems:

   a. $(4 \times 10^{3})^{3} =$ ____________________

   b. $(1 \times 10^{0})^{3} =$ ____________________

c. $(10 \times 10^2)^3 =$ ________________

d. $(.02)^3 =$ ________________

9. Find the square roots:

a. $\sqrt{10 \times 10^1} =$ ________________

b. $\sqrt{4 \times 10^2} =$ ________________

c. $\sqrt{6.4 \times 10^5} =$ ________________

d. $\sqrt{.001} =$ ________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

F. Turn to student text volume 1 and read paragraphs 2-35 through 2-46. Return to this page and answer the following questions.

1. Enter the proper prefix for each power of 10 value.

a. $10^6$ ________________

b. $10^3$ ________________

c. $10^0$ ________________

d. $10^{-3}$ ________________

e. $10^{-6}$ ________________

f. $10^{-12}$ ________________

2. Convert the following values as directed.

a. 3,000 ohms to kilohms ________________

b. 60kV to volts ________________

c. 2mA to uA ________________

d. .600uA to mA ________________

e. 150mW to kilowatts ________________

f. 10M ohms to ohms ________________

g. 5A to uA ________________

h. 100 ohms to k ohms ________________

i. .002mA to A ________________

ADJUNCT GUIDE

**ANSWERS TO E.**

1. exponents

2a. $9.4 \times 10^{5}$ b. $3.004 \times 10^{5}$ c. $4.3 \times 10^{2}$ d. $3.656 \times 10^{1}$

3a. $3.999\,998 \times 10^{-6}$ b. $6.84 \times 10^{6}$ c. $-6.5 \times 10^{1}$ d. $1.24 \times 10^{0}$

4a. $2.3265 \times 10^{1}$ b. $3.0697 \times 10^{2}$ c. $5.6402 \times 10^{3}$

5. numerical coefficient, exponent

6. even

7a. 1 or $1 \times 10^{0}$ b. $4 \times 10^{6}$ c. $2.5 \times 10^{11}$ or $25 \times 10^{10}$

d. $16 \times 10^{-8}$ or $1.6 \times 10^{-7}$

8a. $6.4 \times 10^{10}$ or $64 \times 10^{9}$ b. 1 or $1 \times 10^{0}$ c. $1 \times 10^{9}$ or $1000 \times 10^{6}$

d. $8 \times 10^{-6}$

9a. $1 \times 10^{1}$ b. $2 \times 10^{1}$ c. $8 \times 10^{2}$ d. $3.16 \times 10^{-2}$

If you missed ANY questions, review the material before you continue.

3. The prefix for $10^{-6}$ is:

___ a. Mega ___ c. Micro

___ b. Milli ___ d. Amps

4. The prefix kilo equals:

___ a. $10^{-3}$ ___ c. $10^{-6}$

___ b. $10^{6}$ ___ d. $10^{3}$

5. $10 \times 10^{3}$ ohms is equal to:

___ a. 10 K ohms ___ c. 10 M ohms

___ b. 100 K ohms ___ d. 1 K ohm

6. $200 \times 10^{-3}$ amps is equal to:

___ a. .02 amps ___ c. .2 A

___ b. 200,000 amps ___ d. 200,000 mA

7. $100 \times 10^{6}$ ohms is equal to:

___ a. 100,000,000 ohms ___ c. $100 \times 10^{6}$ megohms

___ b. $100 \times 10^{3}$ milliohms ___ d. 100 megohms

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

G. Turn to student text volume 1 and read paragraphs 2-47 through 2-52. Return to this page and answer the following questions.

1. An equation expressed in numerical terms

___ a. is an axiom.

___ b. does not balance until the final solution is reached.

___ c. must be kept in balance through each step of the solution.

___ d. always produces a positive figure.

2. Axioms are truths or facts that

___ a. are self-evident and require no formal proof.

___ b. must be proved periodically.

___ c. prove all equations are initially out of balance.

___ d. prove the unknown quantity is always expressed as a number.

3. You can add 1,000 to the left side of an equation,

___ a. if you subtract 1,000 from the right side.

___ b. without materially affecting the balance.

___ c. if you put a minus 1,000 on the right side.

___ d. if you add 1,000 to the right side.

4. If you multiply both sides of an equation by the same value,

___ a. you must also divide both sides by the same value.

___ b. the value of both sides is reduced by half.

___ c. you do not change the value of either side of the equation.

___ d. you do not change the equality of the equation.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

**ANSWERS TO F:**

1a. mega  b. kilo  c. unit  d. milli  e. micro  f. pico

2a. 3 k ohms  b. 60,000 volts  c. 2,000 uA  d. .0006 mA  e. .00015 kW
f. 10,000,000 ohms  g. 5,000,000 uA  h. .1 K ohms  i. .000 002 A

3. c  4. d  5. a  6. c  7. a and d

If you missed ANY questions, review the material before you continue.

**ANSWERS TO G:**

1. c  2. a.  3. d  4. d

If you missed ANY questions, review the material before you continue.

H. Turn to student text volume 1 and read paragraphs 2-53 through 2-61. Return to this page and answer the following questions.

1. When you use the transposition process in solving equations,

____ a. the unknown quantities are always moved to the left without changing the sign.

____ b. the sign is changed only when moving terms to the right side.

____ c. you must be careful not to change the sign.

____ d. the sign is always changed when you move terms from one side to the other.

2. Which of the following equations will produce a negative answer?

____ a. $X + 6 = 8$  ____ c. $X - 6 = 4$

____ b. $X + 6 = 4$  ____ d. $X + 1 = 2$

3. Which of the following equations will produce a positive answer?

____ a. $X + 10 = 8$  ____ c. $X + 18 = 13$

____ b. $X + 16 = 16$  ____ d. $X + 12 = 15$

4. Solve for the unknown in each of the following equations:

a. $X + 10 = 18$ ____________

b. $3X + 12 = 24$ ____________

c. $3X - 6 = 9$ ____________

d. $7X - X = 49 - X$ ____________

e. $10X - 15 + 5 = 110$ ________________

f. $3X + 10 = 1$ ________________

g. $X + 16 = 11$ ________________

h. $6X + 10 = 10X - 10$ ________________

i. $4X - 8 = 2X + 10$ ________________

j. $7X - 8 + 4 = 3X + 9 + 15$ ________________

k. $10X - 4 = 100 + 16$ ________________

l. $2X - 9 - 1 + 4 = 3X - 19$ ________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

I. Turn to student text volume 1 and read paragraphs 2-62 through 2-78. Return to this page and answer the following questions.

1. In solving equations, the unknown value is:

___ a. N.
___ b. X.
___ c. Y.
___ d. Any of the above.

2. To solve for I in the equation E = IR, you would:

___ a. multiply both sides by R.
___ b. divide both sides by R.
___ c. divide both sides by E.
___ d. cross multiply.

3. If E is equal to P/I, P is equal to:

___ a. E divided by I.
___ b. E plus I.
___ c. E times I.
___ d. $E^2$ plus I.

4. Given the equation A/B = C/D, solve for C by:

___ a. multiplying both sides by D.
___ b. dividing both sides by D.
___ c. multiplying both sides by B.
___ d. dividing both sides by A.

5. In solving for A in the equation A/B = C/D,

___ a. multiply A x D and B x C.
___ b. divide both sides by B x D.
___ c. divide both sides by B.
___ d. multiply both sides by B.

ADJUNCT GUIDE

**ANSWERS TO H:**

1. d 2. b 3. d

4a. 8 b. 4 c. 5 d. 7 e. 12 f. -3 g. -5 h. 5 i. 9 j. 7 k. 12 l. 13

If you missed ANY questions, review the material before you continue

6. $X_C = \frac{1}{2\pi fC}$ Solve for f. ____________________

7. $X_L = 2\pi fL$ Solve for f. ____________________

8. $P = I^2R$ Solve for I. ____________________

9. If E and I of a circuit are known, ____ can be determined.

___ a. voltage.

___ b. current.

___ c. resistance.

___ d. nothing.

10. When voltage is increased in a circuit and the resistance is held constant, the current will:

___ a. increase.

___ b. decrease.

___ c. stay the same.

___ d. stop.

11. If the resistance in a circuit is doubled, and the voltage applied is doubled, the current will:

___ a. double.

___ b. decrease.

___ c. stay the same.

___ d. stop.

12. Which of the following is NOT a form of Ohm's Law?

___ a. I = ER.

___ b. E = IR.

___ c. R = E/I.

___ d. I = E/R.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

# NOTES

**ADJUNCT GUIDE:**

**ANSWERS TO I:**

1. d
2. b
3. c
4. a
5. d
6. $f = \frac{1}{2\Pi C X_c}$
7. $f = \frac{X_L}{2\Pi L}$
8. $I = \sqrt{\frac{P}{R}}$
9. c
10. a
11. c
12. a

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## ELECTRONIC MATHEMATICS

**QUESTIONS:**

1. Multiply the following and express the answers in powers of 10.

   a. $1000 \times 5000 =$ ______________________

   b. $600 \times 7 \times 10^{-2} =$ ______________________

   c. $9000 \times 400 =$ ______________________

   d. $0.007 \times 3 \times 10^{5} =$ ______________________

   e. $0.005 \times 8 \times 10^{6} =$ ______________________

2. Divide the following and express the answers in powers of 10.

   a. $\frac{48 \times 10^{3}}{6 \times 10^{3}} =$ ______________________

   b. $\frac{36{,}000}{90} =$ ______________________

   c. $\frac{56 \times 10^{8}}{7 \times 10^{2}} =$ ______________________

   d. $\frac{0.009}{0.09} =$ ______________________

   e. $\frac{10{,}000{,}000}{1{,}000} =$ ______________________

3. Complete the following problems:

   a. $E = IR$ Solve for I. ______________________

   b. $P = I^2R$ Solve for I. ______________________

   c. $X_L = 2\pi fL$ Solve for L. ______________________

   d. $X_c = \frac{1}{2\pi fC}$ Solve for f. ______________________

   e. $P = IE$ Solve for E. ______________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

## MODULE SELF-CHECK

### ANSWERS TO MODULE SELF-CHECK

1a. $5 \times 10^6$ b. $4.2 \times 10^{-1}$ c. $3.6 \times 10^6$ d. $2.1 \times 10^3$ e. $4 \times 10^4$

2a. $8 \times 10^0$ b. $4 \times 10^2$ c. $8 \times 10^6$ d. $1 \times 10^{-1}$ e. $1 \times 10^4$

3a. $I = E/R$ b. $I = \sqrt{P/R}$ c. $L = \frac{X_L}{2\pi f}$ d. $f = \frac{1}{2\pi C X_C}$ e. $E = P/I$

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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TECHNICAL TRAINING

Electronic Principles Department

# ELECTRONIC PRINCIPLES/MODULAR SELF-PACED

## MODULE 3

## ELECTRONIC MATHEMATICS

1 July 1974

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 0-0230

DO NOT USE ON THE JOB

# PROGRAMMED TEXT

# ELECTRONIC MATHEMATICS

INSTRUCTIONS:

This text is designed so that you will go through it step by step. Each frame or step of instruction is designed to teach you a small bit of information. Answers for the questions for each frame is given on the top of the next even numbered page. (Blocked.)

Read the information and respond as you are directed. Turn to the following page and confirm your response. Do not proceed until you have responded correctly. If you require assistance, see your instructor.

## CONTENTS

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| Signed Numbers | 1 |
| Powers of Ten | 7 |
| Electronic Prefixes | 26 |
| Equations | 41 |

Supersedes Service Test Edition, KEP-PT-3, 1 April 1974.

## SIGNED NUMBERS

Mathematics is an important tool in the study and understanding of electronics. Certain mathematical operations are more useful than others. This text will explain the following areas: signed numbers, powers of ten, and equations. A basic understanding of these areas will prove to be very helpful in later applications to electronic problems involving formulas.

In order to understand powers of ten, it is necessary to understand signed numbers. Any number may have a positive (+) or negative (-) sign attached to it. The sign indicates a direction from some reference point. The following numbered lines show the relationship between positive and negative numbers. If positive is to the right, then negative is to the left. If positive is up, then negative is down. The positive sign is often omitted. A number without a sign is understood to be positive.

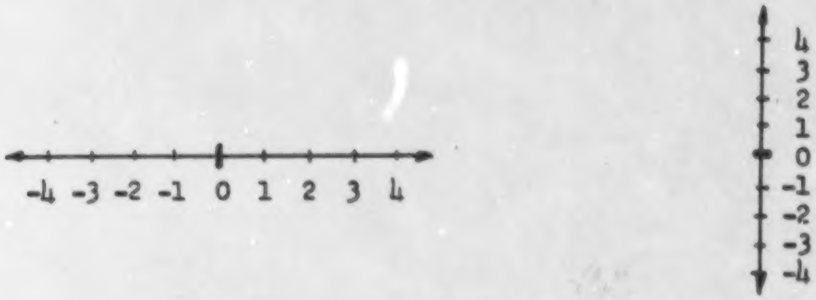

Figure 1. Signed Numbers

Knowledge of the operations of addition, subtraction, and multiplication of signed numbers is the objective of the first part. Your knowledge of addition of signed numbers is tested in Master Quiz 1.

---

MASTER QUIZ 1. ADD:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | -3 | 2. | +6 | 3. | 8 | 4. | -6.2 | 5. | 26 | 6. | -17 |
| | -4 | | -6 | | -15 | | 10.3 | | -12 | | -3.4 |

Check your answers on the next even-numbered page. If you missed less than two, take MASTER QUIZ 2. If you missed two or more, continue reading.

---

Adding Signed Numbers. When adding numbers with the same signs, the answer retains that sign.

| | | | | |
|---|---|---|---|---|
| Examples: | 3 | -7.2 | +4 | -46.82 |
| | 6 | -4.1 | +7 | -13.18 |
| | 9 | -11.3 | +11 | -60.00 |

Adding numbers with unlike signs is accomplished in two steps:

STEP 1. Disregard signs and subtract smaller number from larger number.

STEP 2. Express this answer with the sign of the larger number.

| | | | | |
|---|---|---|---|---|
| Examples: | -17 | 13.2 | 73 | -16 |
| | + 8 | -81.7 | -42 | 24 |
| | - 9 | -68.5 | 31 | 8 |

Remember the two-step approach when adding numbers with unlike signs!

---

SUB QUIZ 1. Add:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 50 | 2. | -33 | 3. | +17 | 4. | -83 | 5. | -13 | 6. | 100 |
| | -23 | | -11 | | +14.2 | | 72 | | 26.5 | | -105 |

Check your answers on the next even-numbered page. If you missed any of the problems, reread preceding paragraphs. If your answers are correct, take MASTER QUIZ 2.

---

MASTER QUIZ 2. Subtract:

| | | | | | |
|---|---|---|---|---|---|
| 1. -8 | 2. -3 | 3. 4.7 | 4. 18 | 5. -2 | 6. -4 |
| +3 | -7 | 1.3 | -27 | +5 | -4 |

Check your answers on the next even-numbered page. If you missed less than two, take MASTER QUIZ 3. If you missed two or more, continue reading.

---

Subtracting Signed Numbers. Subtraction is the opposite (inverse) operation of addition; remember this when subtracting signed numbers. The subtraction problem can be made into an addition problem by changing the sign of the second number and adding it to the first number. For example, -6 -(7) should be written as -6 + (-7) and solved. Remember, change the sign of the number you are subtracting, then add.

Examples: $\begin{array}{r} -6 \\ \underline{-7} \\ 1 \end{array}$ This problem can be written as: $\begin{array}{r} -6 \\ \underline{+7} \\ 1 \end{array}$

7 - (-14) = 21 Solution: 7 + (+14) = 21

-10 - (3) = -13 Solution: -10 + (-3) = -13

11 - 2 = 9 Solution: 11 + (-2) = 9

37 - (-20_ = 57 Solution; 37 + (+20) = 57

Subtraction of signed numbers is simple as long as you remember to change the sign of the second number and add.

ANSWERS TO MASTER QUIZ 1.

1. -7 2. 0 3. -7 4. 4.1 5. 14 6. -20.4

ANSWERS TO SUB QUIZ 1.

1. 27 2. -44 3. 31.2 4. -11 5. 13.5 6. -5

ANSWERS TO MASTER QUIZ 2.

1. -11 2. 4 3. 3.4 4. 45 5. -7 6. 0

---

SUB QUIZ 2. Subtract:

1. $\begin{array}{r} 23.1 \\ \underline{-14.6} \end{array}$ 2. $\begin{array}{r} -37 \\ \underline{-53} \end{array}$ 3. $\begin{array}{r} -8 \\ \underline{6} \end{array}$ 4. $\begin{array}{r} 14.9 \\ \underline{26.3} \end{array}$ 5. $\begin{array}{r} 18 \\ \underline{10.9} \end{array}$ 6. $\begin{array}{r} -107 \\ \underline{-14} \end{array}$

Check your answers on the next even-numbered page. If you missed any of the problems, reread the preceding paragraph. If your answers are correct, take MASTER QUIZ 3.

---

MASTER QUIZ 3. Multiply:

1. $\begin{array}{r} 11 \\ \times\ \underline{10} \end{array}$ 2. $\begin{array}{r} 7 \\ \times\ \underline{-9} \end{array}$ 3. $\begin{array}{r} -13 \\ \times\ \underline{-9} \end{array}$ 4. $\begin{array}{r} -8 \\ \times\ \underline{-4} \end{array}$ 5. $\begin{array}{r} 5 \\ \times\ \underline{-12} \end{array}$ 6. $\begin{array}{r} -5 \\ \times\ \underline{-16} \end{array}$

Check your answers on the next even-numbered page. If you missed less than two, take Summary Quiz 1. If you missed two or more, continue reading.

Multiplying Signed Numbers. When multiplying numbers with like signs (both positive or both negative), a POSITIVE answer will always be the result.

Examples:
$$\begin{array}{r} 3 \\ \times\ 6 \\ \hline 18 \end{array} \qquad \begin{array}{r} -4 \\ \times\ -5 \\ \hline 20 \end{array} \qquad \begin{array}{r} -12 \\ \times\ -11 \\ \hline 132 \end{array} \qquad \begin{array}{r} 8 \\ \times\ .2 \\ \hline 1.6 \end{array}$$

Multiplying numbers with unlike signs will always produce a NEGATIVE answer.

Examples:
$$\begin{array}{r} 5 \\ \times\ -12 \\ \hline -60 \end{array} \qquad \begin{array}{r} -6 \\ \times\ 7 \\ \hline -42 \end{array} \qquad \begin{array}{r} -2.1 \\ \times\ .7 \\ \hline -1.47 \end{array} \qquad \begin{array}{r} 2 \\ \times\ -8 \\ \hline -1.6 \end{array}$$

Remember, multiplying numbers with like signs will produce positive answers, and multiplying numbers of unlike signs will produce negative answers.

---

SUB QUIZ 3. Multiply:

$$1.\ \begin{array}{r} 3 \\ \times\ 7 \\ \hline \end{array} \qquad 2.\ \begin{array}{r} -4 \\ \times\ -9 \\ \hline \end{array} \qquad 3.\ \begin{array}{r} 17 \\ \times\ -11 \\ \hline \end{array} \qquad 4.\ \begin{array}{r} -16 \\ \times\ 4 \\ \hline \end{array} \qquad 5.\ \begin{array}{r} -1.3 \\ \times\ -.2 \\ \hline \end{array} \qquad 6.\ \begin{array}{r} 14 \\ \times\ -3 \\ \hline \end{array}$$

Check your answers on the next even-numbered page. If you missed any of the problems, reread the preceding paragraphs. If your answers are correct, take Summary Quiz 1.

ANSWERS TO SUB QUIZ 2.

1. 37.7  2. 16  3. -14  4. -11.4  5. 7.1  6. -93

ANSWERS TO MASTER QUIZ 3.

1. 110  2. -63  3. 117  4. 32  5. -60  6. 80

ANSWERS TO SUB QUIZ 3.

1. 21  2. 36  3. -187  4. -64  5. .26  6. -42

---

SUMMARY QUIZ 1.

1. Subtract: $\begin{array}{r} -13 \\ \underline{6} \end{array}$  2. Multiply: $\begin{array}{r} 12 \\ \underline{7} \end{array}$  3. Add: $\begin{array}{r} 120 \\ \underline{-14} \end{array}$

4. Multiply: $\begin{array}{r} -3 \\ \underline{-9} \end{array}$  5. Subtract: $\begin{array}{r} 16 \\ \underline{-4} \end{array}$  6. Add: $\begin{array}{r} -76 \\ \underline{-13} \end{array}$

7. Add: $\begin{array}{r} 32.1 \\ \underline{14.8} \end{array}$  8. Multiply: $\begin{array}{r} -17 \\ \underline{4} \end{array}$  9. Subtract: $\begin{array}{r} -37.6 \\ \underline{-36.6} \end{array}$

10. Subtract: $\begin{array}{r} 28 \\ \underline{-20} \end{array}$  11. Multiply: $\begin{array}{r} 6.3 \\ \underline{-.9} \end{array}$  12. Add: $\begin{array}{r} -132 \\ \underline{16} \end{array}$

Check your answers on the next even numbered page. If your answers are correct, go on to the next paragraph. If you missed any problems, review the appropriate paragraphs.

---

Division of signed numbers will not be covered in this text.

# POWERS OF TEN

Powers of ten play a very important role in electronics. For example, there are 6,280,000,000,000, 000, 000 electrons in one coulomb. It is easier to write that number as $6.28 \times 10^{18}$ electrons. You can see that using a power of ten is really a type of mathematical shorthand.

Powers of ten have two purposes when used in electronics. They simplify calculations and provide a convenient method of expressing very large and very small numbers. Look at the following pattern:

$100 = 10 \times 10$

$1000 = 10 \times 10 \times 10$

$10,000 = 10 \times 10 \times 10 \times 10$

$100,000 = 10 \times 10 \times 10 \times 10 \times 10$

and so on. You can simplify writing these numbers by using the following abbreviation: $10 \times 10 = 10^2$. Read $10^2$ as "ten to the second power". $10 \times 10 \times 10 = 10^3$. Read $10^3$ as "ten to the third power". $10 \times 10 \times 10 \times 10 = 10^4$. Read $10^4$ as "ten to the fourth power". $10 = 10^1$ and is read as "ten to the first power. $1 = 10^0$ and is read as "ten to the zero power".

Numbers besides those beginning with one can be written with this shorter method. For example:

$$400 = 4 \times 100 = 4 \times 10^2$$
$$8000 = 8 \times 1000 = 8 \times 10^3$$
$$16 = 1.6 \times 10$$
$$2450 = 2.450 \times 1000 = 2.45 \times 10^3$$

ANSWERS TO SUMMARY QUIZ 1

1. -19 2. 84 3. 106 4. 27 5. 20 6. -89 7. 46.9

8. -68 9. -1 10. 48 11. -5.67 12. -116

Now you can see why we can say that 6,280,000,000,000,000,000, electrons is equal to $6.28 \times 10^{18}$ electrons. The small raised number is called the EXPONENT and 10 is called the BASE NUMBER. The number that is multiplied by the power of ten is called the NUMERICAL COEFFICIENT. Let's locate these numbers with respect to a power of ten.

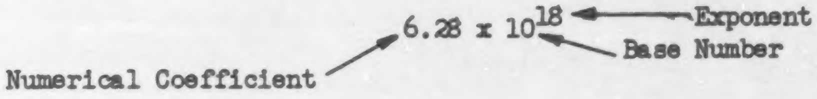

FIGURE 2.

MASTER QUIZ 4. Convert to powers of ten with the numerical coefficient expressed as a number between 1 and 10.

1. 2500 = ____________ 4. .000000825 = ____________

2. 486,000 = ____________ 5. 156.73 = ____________

3. .0028 = ____________ 6. .018 = ____________

Check your answers on the next even-numbered page. If you missed less than two, proceed to MASTER QUIZ 5. If you missed two or more, continue reading.

An easy rule to follow for changing a number greater than ten to a power of ten is:

Move the decimal point so that one non-zero digit remains to the left and count the number of places the decimal was moved. The number of places will be the exponent of the ten.

Let's use this rule to do the following problems:

(1) $427,000 = 4.27000 \times 10^5 = 4.27 \times 10^5$

(2) $18.2 = 1.82 \times 10^1 = 1.82 \times 10$

(3) $5,280,000,000 = 5.280000000 \times 10^9 = 5.28 \times 10^9$

---

SUB QUIZ 4A. Convert to powers of ten expressing the numerical coefficient as a number between 1 and 10.

1. 56,800 = ____________________
2. 310 = ____________________
3. 78,800,000 = ____________________
4. 2400 = ____________________
5. 102450 = ____________________
6. 14.32 = ____________________

Check your answers on the next even-numbered page. If you missed any problems, review the preceding paragraphs. If your answers are correct, continue reading.

---

Powers of ten can also be used to write very small numbers. The following listing explains:

$.1 = 10^{-1}$

$.01 = 10^{-2}$

$.001 = 10^{-3}$

$.0001 = 10^{-4}$

$.00001 = 10^{-5}$

and so on.

The negative exponent shows that the decimal point was moved TO THE RIGHT.

ANSWERS TO MASTER QUIZ 4.

1. $2.5 \times 10^3$
2. $4.86 \times 10^5$
3. $2.8 \times 10^{-3}$
4. $8.25 \times 10^{-7}$
5. $1.5673 \times 10^2$
6. $1.8 \times 10^{-2}$

ANSWERS TO SUB QUIZ 4A.

1. $5.68 \times 10^4$
2. $3.1 \times 10^2$
3. $7.88 \times 10^7$
4. $2.4 \times 10^3$
5. $1.0245 \times 10^5$
6. $1.432 \times 10$

Other small numbers can be written this way:

$.4 = 4 \times .1 = 4 \times 10^{-1}$

$.06 = 6 \times .01 = 6 \times 10^{-2}$

$.0055 = 5.5 \times .001 = 5.5 \times 10^{-3}$

Notice that the numerical coefficient of the power of ten is between one and ten just like the positive exponent problems.

The rule for changing small numbers to powers of ten is:

Move the decimal point so that one non-zero digit appears to the left of the decimal point. Count the number of places the decimal point was moved to the right. The number of places will be the exponent which will also be negative.

The following problems illustrate the rule above.

(1) $.00051 = 5.1 \times 10^{-4}$

(2) $.000000009 = 9 \times 10^{-9}$

(3) $.0206 = 2.06 \times 10^{-2}$

(4) $.10005 = 1.0005 \times 10^{-1}$

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Remember:

(1) The numerical coefficient will always be expressed as a number between one and ten.

(2) If you move the decimal point right, the exponent will be negative.

(3) If you move the decimal point left, the exponent will be positive.

Let's convert the following problems to powers of ten. Remember the rules for positive and negative exponents.

(1) $4527.60 = 4.5276 \times 10^3$

The decimal point was moved 3 places to the LEFT so the exponent is POSITIVE THREE.

(2) $.000513 = 5.13 \times 10^{-4}$

The decimal point was moved 4 places to the RIGHT so the exponent is NEGATIVE FOUR.

---

SUB QUIZ 4B. Convert to powers of ten expressing the numerical coefficient as a number between 1 and 10.

1. .00426 = ________________
2. 18,000 = ________________
3. 3428.5 = ________________
4. .00000082 = ________________
5. .9 = ________________
6. 696,000 = ________________

Check your answers on the next even numbered page. If you missed any of the problems, review the preceding paragraphs. If your answers are correct, take MASTER QUIZ 5.

ANSWERS TO SUB QUIZ 4B.

1. $4.26 \times 10^{-3}$
2. $1.8 \times 10^{4}$
3. $3.4285 \times 10^{3}$
4. $8.2 \times 10^{-7}$
5. $9 \times 10^{-1}$
6. $6.96 \times 10^{5}$

---

MASTER QUIZ 5. Convert from the given power of ten to the power of ten whose numerical coefficient is between 1 and 10.

1. $242 \times 10^{6}$ = ____________
2. $.0034 \times 10^{-3}$ = ____________
3. $72.34 \times 10^{4}$ = ____________
4. $.00006 \times 10^{2}$ = ____________
5. $.379 \times 10^{-5}$ = ____________
6. $5{,}284 \times 10^{-2}$ = ____________

Check your answers on the next even-numbered page. If you missed less than two, proceed to MASTER QUIZ 6. If you missed two or more, continue reading.

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Sometimes a number is written as a power of ten with the numerical coefficient not between one and ten. In this case we must correct the number so that the numerical coefficient is between one and ten. This is done so that a standard answer is attained by everyone.

We use the same rules as before but we must also take into account the exponent already written. Look at the following examples:

(1) $45 \times 10^{5} = 4.5 \times 10^{5+1} = 4.5 \times 10^{6}$

We had to move the decimal point ONE place to the LEFT which gives an exponent of positive one. This exponent is added to the present exponent.

(2) $305 \times 10^{2} = 3.05 \times 10^{2+2} = 3.05 \times 10^{4}$

(3) $.1 \times 10^{4} = 1 \times 10^{4+(-1)} = 1 \times 10^{3}$

In this example the decimal point was moved ONE place to the RIGHT which indicates an exponent of -1. The negative one is added to the +4 already there to get the sum of 3. (If necessary, review addition of signed numbers in preceding paragraphs.)

(4) $.051 \times 10^{-2} = 5.1 \times 10^{-2+(-2)} = 5.1 \times 10^{-4}$

In each case, determine the proper exponent using the rules you have learned in preceding paragraphs. Then add this new exponent to the exponent already in the problem.

Let's try a few problems:

(1) .0037 x $10^{-2}$ = 3.7 x $10^{-5}$ **Solution:** The decimal point had to be moved 3 places to the RIGHT so the new exponent is -3. Add -3 to -2 already in the problem to get -5.

(2) 5342.76 x $10^{5}$ = 5.34276 x $10^{8}$ **Solution:** The decimal point has to be moved 3 places to the LEFT for an exponent of +3. The +3 is added to the 5 in the problem to get 8.

(3) .0000502 x $10^{4}$ = 5.02 x $10^{-1}$ **Solution:** The decimal point has to be moved 5 places to the RIGHT for an exponent of -5. The -5 is added to the 4 already there to get an exponent of -1.

---

SUB QUIZ 5. Convert the given power of ten to a power of ten having a numerical coefficient between 1 and 10.

1. .037 x $10^{3}$ = ______ 4. .00005 x $10^{-2}$ = ______
2. 1000 x $10^{-7}$ = ______ 5. .364 x 10 = ______
3. 54.76 x $10^{4}$ = ______ 6. 99865 x $10^{-3}$ = ______

Check your answers on the next even-numbered page. If you missed an answer, reread the preceding paragraphs. If your answers are correct, take MASTER QUIZ 6.

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MASTER QUIZ 6. Multiply using powers of ten to express the answer's numerical coefficient as a number between 1 and 10.

1. 4300 x 17 = ______. 4. 2.1 x $10^{-3}$ x 2 x $10^{2}$ = ______
2. .004 x 3000 = ______. 5. .5 x (9x$10^{-4}$) = ______
3. 10.5 x (5 x $10^{2}$)= ______. 6. 4000 x .00004 = ______

Check your answers on the next even-numbered page. If you missed less than two, take MASTER QUIZ 7. If you missed two or more, continue reading.

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**ANSWERS TO MASTER QUIZ 5.**

1. $2.42 \times 10^8$
2. $3.4 \times 10^{-6}$
3. $7.234 \times 10^5$
4. $6 \times 10^{-3}$
5. $3.79 \times 10^{-6}$
6. $5.284 \times 10$

**ANSWERS TO SUB QUIZ 5.**

1. $3.7 \times 10$
2. $1.0 \times 10^{-4}$
3. $5.476 \times 10^5$
4. $5 \times 10^{-7}$
5. $3.64 \times 10^0 = 3.64$
6. $9.9865 \times 10^1$

**ANSWERS TO MASTER QUIZ 6.**

1. $7.31 \times 10^4$
2. $1.2 \times 10$
3. $5.25 \times 10^3$
4. $4.2 \times 10^{-1}$
5. $4.5 \times 10^{-4}$
6. $1.6 \times 10^{-1}$

Multiplication using powers of ten involves four basic steps:

(1) Convert numbers to powers of ten if not already in that form.

(2) MULTIPLY the numerical coefficients.

(3) ADD the exponents.

(4) Express the answer with a numerical coefficient between 1 and 10.

Example 1. $.0007 \times 24 =$ ____________________.

(1) Convert to powers of ten. $.0007 = 7 \times 10^{-4}$ $24 = 2.4 \times 10$

(2) MULTIPLY numerical coefficients $(7 \times 10^{-4}) \times (2.4 \times 10^{1})$

$= 16.8 \times 10^{-4} \times 10^{1}$

(3) ADD exponents. $16.8 \times 10^{-4} \times 10^{1} = 16.8 \times 10^{(-4 + 1)} = 16.8 \times 10^{-3}$

(4) Express the answer's numerical coefficient as a number between 1 and 10. $16.8 \times 10^{-3} = 1.68 \times 10^{-2}$

(Moving the decimal point left one place means you add a positive one to the exponent.)

Example 2. 55,000 x 3,300 = ______________________.

(1) Convert to powers of ten. $55{,}000 = 5.5 \times 10^{4}$ $3{,}300 = 3.3 \times 10^{3}$

(2) Multiply numerical coefficients. $(5.5 \times 10^{4}) \times (3.3 \times 10^{3})$

$= 18.15 \times 10^{4} \times 10^{3}$

(3) ADD exponents. $18.15 \times 10^{4} \times 10^{3} = 18.15 \times 10^{(4 + 3)} = 18.15 \times 10^{7}$

(4) Express the answer's numerical coefficient as a number between 1 and 10. $18.15 \times 10^{7} = 1.815 \times 10^{8}$

Example 3. $.0067 \times 2.8 \times 10^{-5}$

(1) Convert to powers of ten. $.0067 = 6.7 \times 10^{-3}$

(2) Multiply numerical coefficients. $(6.7 \times 10^{-3}) \times (2.8 \times 10^{-5})$

$= 18.76 \times 10^{-3} \times 10^{-5}$

(3) Add exponents. $18.76 \times 10^{-3} \times 10^{-5} = 18.76 \times 10^{(-3) + (-5)}$

$= 18.76 \times 10^{-8}$

(4) Express the answer's numerical coefficient as a number between 1 and 10. $18.76 \times 10^{-8} = 1.876 \times 10^{-7}$

Example 4. 200,000 x .045

(1) Convert to powers of ten. 200,000 = $2 \times 10^5$ .045 = $4.5 \times 10^{-2}$

(2) Multiply numerical coefficients. $(2 \times 10^5) \times (4.5 \times 10^{-2})$

$$= 9 \times 10^5 \times 10^{-2}$$

(3) Add exponents. $9 \times 10^5 \times 10^{-2} = 9 \times 10^{5+(-2)} = 9 \times 10^3$

(4) This step is not necessary.

In solving any multiplication problem using powers of ten, the same four steps are always used. Also, remember that the exponents are signed numbers and should be treated as such when adding them. You can review addition of signed numbers in preceding paragraphs.

---

SUB QUIZ 6. Multiply using powers of ten.

1. 36,000 x 500,000 = ____________________
2. .0005 x 2,000 = ____________________
3. $2.5 \times 10^{-4} \times 2.1 \times 10^{-5}$ = ____________________
4. .035 x .00087 = ____________________
5. $4.85 \times 10^5 \times 9 \times 10^{-2}$ = ____________________
6. 4500 x 10,000 = ____________________

Check your answers on the next even-numbered page. If you missed an answer, reread the preceding paragraphs. If your answers are correct, take MASTER QUIZ 7.

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MASTER QUIZ 7. Divide using powers of ten with the answer's numerical coefficient expressed as a number between 1 and 10.

1. $\frac{6000}{300}$ = ____________

2. $.0018 \div .0009$ = ____________

3. $\frac{18 \times 10^{7}}{3 \times 10^{-4}}$ = ____________

4. $\frac{8 \times 10^{-7}}{2 \times 10^{3}}$ = ____________

5. $\frac{.03}{4{,}000{,}000}$ = ____________

6. $\frac{.00012}{.05}$ = ____________

Check your answers on the next even-numbered page. If you missed less than two, take MASTER QUIZ 8. If you missed two or more, continue reading.

---

A division problem can be written in one of two ways: $5000 \div 25$ or $\frac{5000}{25}$. We will utilize the second form in our discussion. The number above the line is called the numerator and the number below the line is called the denominator.

Division using powers of ten is very similar in procedure to multiplication using powers of ten. Four basic steps are used:

(1) Convert the numbers to powers of ten if not already in that form.

(2) Divide the numerical coefficients.

(3) Move the exponent in the denominator above the line, change its sign, and add to the exponent in the numerator.

(4) Express the answer's numerical coefficient as a number between 1 and 10 times the correct power of ten.

**ANSWERS TO SUB QUIZ 6.**

1. $1.8 \times 10^{10}$
2. $1$
3. $5.25 \times 10^{-9}$
4. $3.04 \times 10^{-5}$
5. $4.365 \times 10^{4}$
6. $4.5 \times 10^{7}$

**ANSWERS TO MASTER QUIZ 7.**

1. $2 \times 10$
2. $2$
3. $6 \times 10^{11}$
4. $4 \times 10^{-10}$
5. $7.5 \times 10^{-9}$
6. $2.4 \times 10^{-3}$

Example 1. $\dfrac{.0000054}{.00009}$

(1) Convert to powers of ten. $\dfrac{.0000054}{.00009} = \dfrac{5.4 \times 10^{-6}}{9 \times 10^{-5}}$

(2) Divide the numerical coefficients. $\dfrac{5.4 \times 10^{-6}}{9 \times 10^{-5}} = .6 \times \dfrac{10^{-6}}{10^{-5}}$

(3) Move the exponent in the denominator above the line, change its sign, and add to the exponent in the numerator.

$$.6 \times \frac{10^{-6}}{10^{-5}} = .6 \times 10^{-6} \times 10^{+5} = .6 \times 10^{-6+(+5)} = .6 \times 10^{-1}$$

(4) Express the answer's numerical coefficient between 1 and 10.

$$.6 \times 10^{-1} = 6 \times 10^{-2}$$

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Example 2. $\dfrac{35000}{25}$

(1) Convert to powers of ten. $\dfrac{3.5 \times 10^4}{2.5 \times 10^1}$

(2) Divide numerical coefficients. $\dfrac{3.5 \times 10^4}{2.5 \times 10^1} = 1.4 \times \dfrac{10^4}{10^1}$

(3) Move the exponent in the denominator above the line, change its sign, and add to the exponent in the numerator.

$$1.4 \times \frac{10^4}{10^1} = 1.4 \times 10^4 \times 10^{-1} = 1.4 \times 10^{4+(-1)} = 1.4 \times 10^3$$

(4) This step is unnecessary as the answer is already in proper form.

Example 3. $\dfrac{.0018}{.0009}$

(1) Convert to powers of 10. $\dfrac{1.8 \times 10^{-3}}{9 \times 10^{-4}}$

(2) Divide the numerical coefficients. $\dfrac{1.8 \times 10^{-3}}{9 \times 10^{-4}} = .2 \times \dfrac{10^{-3}}{10^{-4}}$

(3) Move the denominator above the line, change the sign of its exponent, and add it to the numerator's exponent.

$$.2 \times \frac{10^{-3}}{10^{-4}} = .2 \times 10^{-3} \times 10^4 = .2 \times 10^{(-3+4)} = .2 \times 10^1$$

(4) Express the answer's numerical coefficient as a number between 1 and 10. $.2 \times 10^1 = 2 \times 10^0 = 2$

Example 4. $\frac{.0000072}{.004}$

(1) Convert to powers of ten. $\frac{7.2 \times 10^{-6}}{4 \times 10^{-3}}$

(2) Divide the numerical coefficients. $\frac{7.2 \times 10^{-6}}{4 \times 10^{-3}} = 1.8 \times \frac{10^{-6}}{10^{-3}}$

(3) Move the denominator above the line, change the sign of its exponent, and add it to the numerator's exponent.

$$1.8 \times \frac{10^{-6}}{10^{-3}} = 1.8 \times 10^{-6} \times 10^{3} = 1.8 \times 10^{(-6+3)} = 1.8 \times 10^{-3}$$

(4) This step is not necessary as the number is already in correct form.

Example 5. $\frac{80,000}{.0000002}$

$$\begin{aligned} \frac{80,000}{.0000002} = \frac{8 \times 10^{4}}{2 \times 10^{-7}} = 4 \times \frac{10^{4}}{10^{-7}} &= 4 \times 10^{4} \times 10^{7} \\ &= 4 \times 10^{(4+7)} \\ &= 4 \times 10^{11} \end{aligned}$$

Example 6. $\frac{.00009}{450}$

$$\begin{aligned} \frac{.00009}{450} = \frac{9 \times 10^{-5}}{4.5 \times 10^{2}} = 2 \times \frac{10^{-5}}{10^{2}} &= 2 \times 10^{-5} \times 10^{-2} \\ &= 2 \times 10^{-5 + (-2)} \\ &= 2 \times 10^{-7} \end{aligned}$$

Remember: You must change the sign of the denominator's exponent when you move it to the top and add it to the numerator's exponent.

Utilize the four-step approach when solving division problems. Sometimes steps 1 and 4 are not necessary, but steps 2 and 3 ALWAYS are!

---

SUB QUIZ 7. Divide using powers of ten.

1. $\frac{32,000}{.008}$ = ____________
2. $\frac{.110}{2000}$ = ____________
3. $\frac{.000009}{.00000003}$ = ____________
4. $\frac{800}{1,600,000}$ = ____________
5. $\frac{.0027}{.0003}$ = ____________
6. $\frac{.00024}{720}$ = ____________

Check your answers on the next even-numbered page. If you missed an answer, review the preceding paragraphs. If your answers are correct, take MASTER QUIZ 8.

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MASTER QUIZ 8. Addition and Subtraction using powers of ten.

1. 340,000 + 75,000 = ____________
2. $90 \times 10^4 + 6 \times 10^5$ = ____________
3. .0076 + .00045 = ____________
4. $4 \times 10^{-6} - 2 \times 10^{-4}$ = ____________
5. 5 - .002 = ____________
6. $7.8 \times 10^6 - 96 \times 10^4$ = ____________

Check your answers on the next even-numbered page. If you missed less than two, proceed to MASTER QUIZ 9. If you missed two or more continue reading.

---

Addition and subtraction using powers of ten involve four basic steps.

(1) Convert the numbers to powers of ten if not already in that form.

(2) Convert the numbers to the SAME power of ten.

(3) Add or subtract the numerical coefficients and retain the same power of ten in the answer.

ANSWERS TO SUB QUIZ 7.

1. $4 \times 10^6$
2. $5.5 \times 10^{-5}$
3. $3 \times 10^2$
4. $5 \times 10^{-4}$
5. 9
6. $3.3 \times 10^{-7}$

ANSWERS TO MASTER QUIZ 8.

1. $4.15 \times 10^5$
2. $1.5 \times 10^6$
3. $8.05 \times 10^{-3}$
4. $-1.96 \times 10^{-4}$
5. 4.998
6. $6.84 \times 10^6$

(4) Express the answer with a numerical coefficient between 1 and 10.

Steps one and two may be accomplished at the same time.

Example 1. 54000 + 8400

(1) and (2) Convert the numbers to the SAME power of ten.

$$54000 = 5.4 \times 10^4 = 54 \times 10^3 \qquad 8400 = 8.4 \times 10^3$$

(3) Add the coefficients while retaining the like power of ten.

$$(54 \times 10^3) + (8.4 \times 10^3) = (54 + 8.4) \times 10^3 = 62.4 \times 10^3$$

(4) Express answer's numerical coefficient as a number between 1 and 10. $62.4 \times 10^3 = 6.24 \times 10^4$

Example 2. $90 \times 10^{-4} + 40 \times 10^{-5}$

(1) Not necessary.

(2) Express numbers with the same power of ten.

$90 \times 10^{-4} + 40 \times 10^{-5} = 90 \times 10^{-4} + 4 \times 10^{-4}$

(3) Add the numerical coefficients retaining the like power of ten.

$(90 \times 10^{-4}) + (4 \times 10^{-4}) = (90 + 4) \times 10^{-4} = 94 \times 10^{-4}$

(4) Express the answer's numerical coefficient as a number between 1 and 10. $94 \times 10^{-4} = 9.4 \times 10^{-3}$

To subtract numbers that contain powers of ten, the same principles apply as used in addition except you subtract the numerical coefficients.

Example 3. .0125 - .0036

(1) Convert to powers of ten. $.0125 = 1.25 \times 10^{-2}$

$.0036 = 3.6 \times 10^{-3}$

(2) Express the numbers with the same power of ten.

$1.25 \times 10^{-2} - 3.6 \times 10^{-3} = 12.5 \times 10^{-3} - 3.6 \times 10^{-3}$

(3) Subtract the numerical coefficients retaining the like power of ten. $(12.5 \times 10^{-3}) - (3.6 \times 10^{-3})$

$= (12.5 - 3.6) \times 10^{-3}$

$= 8.9 \times 10^{-3}$

(4) Not necessary.

---

SUB QUIZ 8. Add or Subtract using powers of ten as indicated.

1. $3.6 \times 10^{1} + 5.6 \times 10^{-1} =$ ____________________
2. $13 \times 10^{-1} - 6 \times 10^{-2} =$ ____________________
3. $.00043 + .00273 =$ ____________________
4. $825{,}000 - 7990 =$ ____________________
5. $5 \times 10^{0} - 7 \times 10^{1} =$ ____________________
6. $4 \times 10^{2} + 3 \times 10^{5} =$ ____________________

Check your answers on the next even-numbered page. If you missed an answer, review preceding paragraphs before continuing. If your answers are correct, take MASTER QUIZ 9.

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MASTER QUIZ 9. Express your final answers with the numerical coefficients between 1 and 10.

1. $(2 \times 10^{3})^{2} =$ ____________ 4. $\sqrt{4 \times 10^{4}} =$ ____________
2. $(.002)^{3} =$ ____________ 5. $\sqrt{10 \times 10^{5}} =$ ____________
3. $(5 \times 10^{5})^{2} =$ ____________ 6. $\sqrt{1.6 \times 10^{1}} =$ ____________

Check your answers on the next even-numbered page. If you missed less than two, begin further study with Electronic Prefixes. If you missed two or more, continue reading.

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To square a number containing a power of ten, first square the numerical coefficient and then multiply the exponent by 2.

Examples: $(3 \times 10^4)^2 = (3)^2 \times (10^4)^2 = 3 \times 3 \times (10^4)^2 = 9 \times 10^8$

$$(.006)^2 = (6 \times 10^{-3})^2 = (6)^2 \times (10^{-3})^2 = 6 \times 6 \times (10^{-3})^2$$

$$= 36 \times 10^{-6} = 6 \times 10^{-5}$$

To cube a number, cube the numerical coefficient and then multiply the exponent of ten by 3.

Examples: $(4 \times 10^3)^3 = (4)^3 \times (10^3)^3 = 64 \times 10^9 = 6.4 \times 10^{10}$

$$(200)^3 = (2 \times 10^2)^3 = (2)^3 \times (10^2)^3 = 8 \times 10^6$$

To take the square root of a number with a power of ten, first take the square root of the numerical coefficient and then divide the exponent of ten by 2.

Examples: $\sqrt{9 \times 10^4} = \sqrt{9} \times \sqrt{10^4} = 3 \times 10^{4/2} = 3 \times 10^2$

$$\sqrt{400 \times 10^6} = \sqrt{400} \times \sqrt{10^6} = 20 \times 10^{6/2} = 20 \times 10^3 = 2 \times 10^4$$

For your convenience, square root tables are provided in the KEP 110, ELECTRONICS HANDBOOK beginning on page 120.

Suppose you wanted to solve this problem: $\sqrt{250 \times 10^3}$ . One-half an odd-number exponent produces a fractional exponent for the power of ten. Therefore, to extract a square root, the exponent must be an even number. To convert to an even exponent, you move the decimal point one place.

$$\sqrt{250 \times 10^3} = \sqrt{25 \times 10^4} = \sqrt{25} \times \sqrt{10^4} = 5 \times 10^{4/2} = 5 \times 10^2$$

Examples: $\sqrt{.000049} = \sqrt{49 \times 10^{-6}} = \sqrt{49} \times \sqrt{10^{-6}} = 7 \times 10^{-6/2} = 7 \times 10^{-3}$

$$\sqrt{1000 \times 10^7} = \sqrt{100 \times 10^8} = 10 \times 10^4 = 1 \times 10^5$$

$$\sqrt{.81 \times 40,000} = \sqrt{81 \times 10^{-2}} \times \sqrt{4 \times 10^4} = 9 \times 10^{-1} \times 2 \times 10^2$$

$$= 18 \times 10^1 = 1.8 \times 10^2$$

$$\sqrt{.000015} = \sqrt{15 \times 10^{-6}} = 3.87 \times 10^{-2}$$

ANSWERS TO SUB QUIZ 8.

1. $3.656 \times 10$
2. $1.24$
3. $3.16 \times 10^{-3}$
4. $8.1701 \times 10^{5}$
5. $-6.5 \times 10$
6. $3.004 \times 10^{5}$

ANSWERS TO MASTER QUIZ 9.

1. $4 \times 10^{6}$
2. $8 \times 10^{-9}$
3. $2.5 \times 10^{11}$
4. $2 \times 10^{2}$
5. $1 \times 10^{3}$
6. $4$

---

SUB QUIZ 9. Solve using powers of ten.

1. $(8 \times 10^{-1})^2 =$ ____________________
2. $\sqrt{.0009} =$ ____________________
3. $(500)^3 =$ ____________________
4. $\sqrt{160 \times 10^3} =$ ____________________
5. $(.0007)^2 =$ ____________________
6. $(6 \times 10^2)^3 =$ ____________________

Check your answers on the next even-numbered page. If you missed an answer, review preceding paragraphs before continuing. If your answers are correct, proceed to next paragraph.

## ELECTRONIC PREFIXES

In your study of powers of ten, you learned that they simplified calculations and provided a convenient method of expressing large and small numbers. Electronic technicians use certain powers of ten so often that special "names" and symbols are used to represent them.

These special names and symbols are called prefixes and are used with standard units of measure. Shortly you will be studying electrical terms such as resistance, current, and voltage. These are just three of many terms that refer to electrical values that may be found in circuits. These values all have their own units of measure. For example, voltage is measured in volts, current in amperes, and resistance in ohms.

Sometimes these units of measure will be very large in quantity or very small. For instance, you could write one thousand volts as 1000 volts. Even this could be shortened by using a prefix and an abbreviation.

The prefix for a thousand is KILO symbolized by k. The letter V represents volts. Note the following:

1000 volts = 1 kilovolt = 1 kV

As you can see, 1 kV is much shorter to write than 1000 volts.

Kilo, since it represents a thousand, is a very common prefix in electronics. Besides kilovolts, you will have kilohms of resistance, kilowatts of power, and kilohertz.

Other powers of ten along with their numerical equivalents, prefixes, and symbols are listed in table . 1. These will help you determine component values in circuits you will study later.

ANSWERS TO SUB QUIZ 9.

1. $6.4 \times 10^{-1}$
2. $3 \times 10^{-2}$
3. $1.25 \times 10^{8}$
4. $4 \times 10^{2}$
5. $4.9 \times 10^{-7}$
6. $2.16 \times 10^{8}$

TABLE 1

| NUMBER | POWER OF TEN | PREFIX | SYMBOL |
|---|---|---|---|
| 1,000,000,000,000 | $10^{12}$ | tera | T |
| 1,000,000,000 | $10^{9}$ | giga | G |
| 1,000,000 | $10^{6}$ | mega | M |
| 1,000 | $10^{3}$ | kilo | k |
| 100 | $10^{2}$ | hecto | h |
| 10 | $10^{1}$ | deka | da |
| .1 | $10^{-1}$ | deci | d |
| .01 | $10^{-2}$ | centi | c |
| .001 | $10^{-3}$ | milli | m |
| .000001 | $10^{-6}$ | micro | $\mu$ |
| .000000001 | $10^{-9}$ | nano | n |
| .000000000001 | $10^{-12}$ | pico | p |

Five of the prefixes in Table 1 are more commonly used in electronics then the others, and are worthy of your study at this time. These are listed in Table 2.

TABLE 2

| NUMBER | POWER OF TEN | PREFIX | SYMBOL |
|---|---|---|---|
| 1,000,000 | $10^6$ | mega | M |
| 1,000 | $10^3$ | kilo | k |
| .001 | $10^{-3}$ | milli | m |
| .000001 | $10^{-6}$ | micro | $\mu$ |
| .000000000001 | $10^{-12}$ | pico | p |

Figure 3 shows how the prefixes appear when presented on a number line. Note that $10^0$, or 1, is the units place and can represent such measures as ohms, volts, amperes, and watts. Moving left from units you have positive exponents, and moving right from units you find negative exponents.

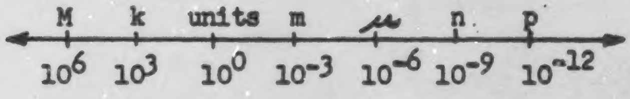

FIGURE 3.

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REVIEW QUIZ. Enter the proper prefix and its symbol for each power of ten given.

1. $10^6$ = ____________________

2. $10^3$ = ____________________

3. $10^0$ = ____________________

4. $10^{-3}$ = ____________________

5. $10^{-6}$ = ____________________

6. $10^{-12}$ = ____________________

Check your answers on the next even-numbered page.

If you missed any of the answers, review preceding paragraphs. If your answers are correct, take MASTER QUIZ 10.

ANSWERS TO REVIEW QUIZ.

1. Mega - M
2. Kilo - k
3. None
4. Mili - m
5. Micro - μ
6. pico - p

---

MASTER QUIZ 10. Convert the following values as directed.

1. 5A to μA = ________________
2. 60 kV to volts = ______________
3. 300 kΩ to MΩ = ______________
4. 150 mW to kW = ______________
5. 600 μA to mA = ______________
6. 100Ω to kΩ = ______________

Check your answers on the next even-numbered page. If you missed less than two, take MASTER QUIZ 11. If you missed more than two, continue reading.

---

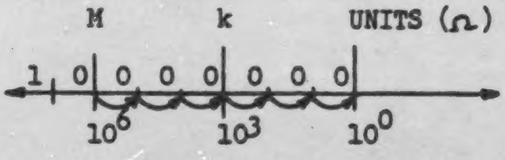
Now that you know the prefixes you must be able to use them in practical applications. You should be able to write a number using the proper prefix, convert one prefix to another, and write a prefix in its numerical form.

To write a number as a prefix you must write the number to the necessary power of ten. The prefixes with their respective powers are listed in Table 2 of the previous section. For example, 1000 = $10^3$ = kilo (k). Therefore, 1000 volts = $10^3$ volts = 1 kilovolt = 1 kV.

Let's work another example. Convert 10,000,000Ω to MΩ.

1. M(mega) = $10^6$
2. 10,000,000Ω = 10 x $10^6$Ω (The decimal point was moved 6 places to the left so the power of ten is +6.)
3. 10 x $10^6$Ω = 10 MΩ

This problem can be shown graphically on the number line.



By placing the number on the number line in its proper place as shown, you can see the following:

10,000,000Ω = 10 MΩ

10,000,000Ω = 10,000 kΩ

Therefore, you can also use the number line in solving these conversions. Remember, the units position ($10^0$) is the unit of measure being used. There is no prefix for this power of ten.

The following steps should be taken in converting from numbers to prefixes.

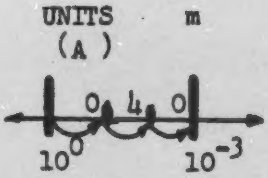
1. Convert the desired prefix to its power of ten.
2. Move the decimal point left (+) or right (-) the necessary number of places.
3. Express the answer using the prefix and the unit of measure.

**ANSWERS TO MASTER QUIZ 10.**

1. 5,000,000 $\mu$A
2. 60,000 V
3. .3 M$\Omega$
4. .00015 kW
5. .6 mA
6. .1 k$\Omega$

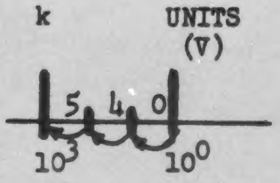
**Example 1.** Convert .04A to mA

1. m(milli) = $10^{-3}$
2. .04A = 4 x $10^{-2}$A = 40 x $10^{-3}$ A
3. 40 x $10^{-3}$ A = 40 mA



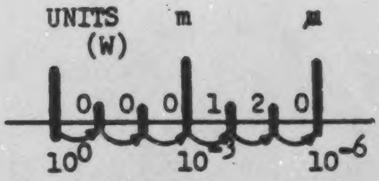
**Example 2.** Convert 540V to kV

1. k (kilo) = $10^3$
2. 540V = .540 x $10^3$ V
3. .540 x $10^3$ V = .54kV



Example 3. Convert .00012W to $\mu$W

1. $\mu$ (micro) = $10^{-6}$
2. .00012W = $12 \times 10^{-5}$ W = $120 \times 10^{-6}$ W
3. $120 \times 10^{-6}$ W = 120 $\mu$W



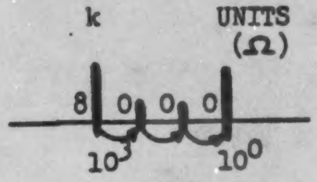
Now that you see how to convert a number to a prefix, changing a prefix to a number shouldn't be difficult. Any time you change a number with a prefix back to units, you just have to reverse your process.

Let's look at the following examples.

Example 1. Convert 8 k$\Omega$ to $\Omega$

1. 8k$\Omega$ = $8 \times 10^3 \Omega$
2. To convert this back to units ($\Omega$), the decimal point should be moved right (-) 3 places to cancel the positive exponent.

   $8 \times 10^3 \Omega$ = 8000 $\Omega$
3. 8 k$\Omega$ = 8000 $\Omega$



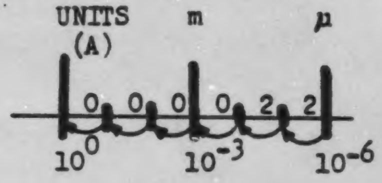
Example 2. Convert 22 $\mu$A to A

1. 22 $\mu$A = 22 x $10^{-6}$ A

2. Move the decimal point left (+) 6 places to cancel the exponent.

$$22 \times 10^{-6}\ A = .000022A$$

3. 22 $\mu$A = .000022A



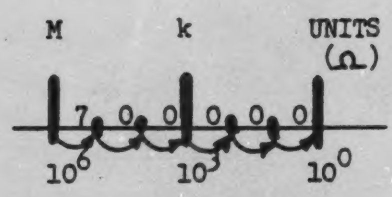
Example 3. Convert .7 M$\Omega$ to $\Omega$

1. .7 M$\Omega$ = .7 x $10^6\Omega$

2. Move the decimal point right (-) 6 places to cancel the exponent.

$$.7 \times 10^6\Omega = 700000\Omega$$

3. .7 M$\Omega$ = 700,000$\Omega$



Remember when changing from a prefix to units, always move the decimal point the direction that would be the opposite of the power of ten indicated by the prefix. This will cancel the prefix and the result is $10^0$ or units position.

Another situation encountered in prefix study is that of converting from a given prefix to another prefix. For instance, you solve a problem on resistance and obtain an answer in M$\Omega$, but the answer should be expressed in k$\Omega$.

Converting from one prefix to another is a simple problem if you understand the previous areas of study. The steps to follow are very similar to those you just studied. Study the following example:

Example 1. Convert .07 M$\Omega$ to k$\Omega$

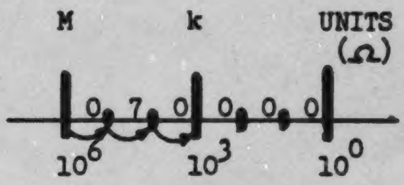
1. Express the prefixes as their powers of ten.

   $M = 10^6$ $k = 10^3$

2. Move the decimal point right 3 places to express the number with the new power of ten.

   $.07 \times 10^6 = 70 \times 10^3$

3. $.07\ M\Omega = .07 \times 10^6\ \Omega = 70 \times 10^3\ \Omega = 70\ k\Omega$



After converting the prefixes to their respective powers of ten, the most important step is to move the decimal point in the right direction. Again you will use a previous rule --- moving the decimal point left produces a larger exponent and moving a decimal point right produces a smaller exponent.

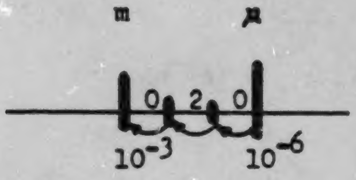
**Example 2.** Convert 20 $\mu$-A to mA

1. $\mu = 10^{-6}$ $m = 10^{-3}$ $20\ \mu A = 20 \times 10^{-6}$ A

2. Since m ($10^{-3}$) is THREE powers greater than $\mu$ ($10^{-6}$), the decimal point should be moved left (+) THREE places.

   $20 \times 10^{-6}$ A = $.020 \times 10^{-3}$ A

3. $20\ \mu A = 20 \times 10^{-6}$ A = $.02 \times 10^{-3}$ A = .02 mA



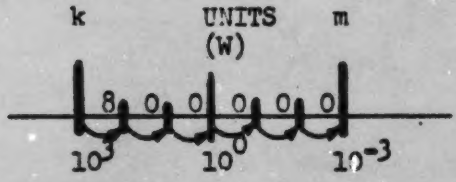
**Example 3.** Convert .8 kW to mW

1. .8 kW = $.8 \times 10^{3}$ W $k = 10^{3}$ $m = 10^{-3}$

2. The decimal point should be moved right (-) SIX places, because m ($10^{-3}$) is SIX powers less than k ($10^{3}$).

   $.8 \times 10^{3}$ W = $800{,}000 \times 10^{-3}$ W

3. .8 kW = $.8 \times 10^{3}$ W = $800{,}000 \times 10^{-3}$ W = 800,000 mW



Remember, a larger exponent tells you to move the decimal point left. The decimal point is moved right for a smaller exponent. The number of places of movement is the difference between the two exponents.

---

SUB QUIZ 10. Convert the following values as directed.

1. 2 mA to $\mu$A
2. 125V to MV
3. 250 mW to W
4. .015 A to mA
5. 625 pF to $\mu$F
6. 3 k$\Omega$ to $\Omega$
7. 75 $\mu$A to A
8. .32 kV to MV
9. 20,000$\Omega$ to M$\Omega$
10. .004 A to $\mu$A
11. 370 kW to W
12. .3 M$\Omega$ to k$\Omega$

Check your answers on the next even-numbered page. If your answers are correct, begin reading the following paragraph. If you missed an answer, review the preceding paragraphs.

---

## MULTIPLICATION AND DIVISION WITH PREFIXES

Prefixes, since they represent powers of ten, are used as a shorthand method of expressing large and small numbers. In electronics, prefixes are used in conjunction with units of measure. A review of an earlier example should show this.

$$1000 \text{ volts} = 1 \times 10^3 \text{ V} = 1 \text{ kV}$$

Values such as 1 kV are used along with other values in solving electronic formulas. Of course, it is necessary to know the prefixes and their respective powers of ten to do the solutions. In order to solve these formulas, you must substitute the power of ten for each prefix into the formulas and work them as power of ten problems. Study the following example.

ANSWERS TO SUB QUIZ 10.

1. 2000 μA
2. .000125 MV
3. .25 W
4. 15 mA
5. .000625 μF
6. 3000 Ω
7. .000075 A
8. .00032 MV
9. .02 MΩ
10. 40 μA
11. 370,000 W
12. 300 kΩ

Example 1. $P = I \times E$ $\quad I = 2$ mA $\quad E = 20$ V $\quad P =$ ________ W

$$
\begin{aligned}
P &= 2 \text{ mA} \times 20 \text{ V} \\
&= 2 \times 10^{-3} \text{ A} \times 20 \text{ V} \\
&= (2 \times 20) \times 10^{-3} \\
&= 40 \times 10^{-3} \text{ W} = 40 \text{ mW or } .04 \text{ W}
\end{aligned}
$$

Review of multiplication using powers of ten paragraphs and division using powers of ten paragraphs may prove helpful.

---

MASTER QUIZ 11. Solve the formulas for the indicated values.

1. $I=E/R$, $E = 150$V, $R = 25$ kΩ, $I =$ ______ mA or ______ A.
2. $t = 1/f$, $f = .5$ megahertz (MHz), $t =$ ________ μs or __________ ms
3. $P = I^2R$, $I = 3$ mA, $R = 7$ kΩ, $P =$ __________ mW or ___________ W.
4. $X_C = \dfrac{.159}{fC}$, $f = 53$ hertz (Hz), $C = 15$ μF (uF), $X_C =$ _____ kΩ or _____ Ω
5. $E = I \times R$, $I = 10$ μA, $R = 425$ kΩ, $E =$ _______ mV or _________ V
6. $\lambda = \dfrac{V}{f}$, $V = 300 \times 10^6$ meters per second, $f = 25$ kHz, $\lambda =$ _______ k meters. or ______ meters.

Check your answers on the next even-numbered page. If you missed less than two, proceed to paragraph covering EQUATIONS. If you missed two or more, continue reading.

Solve the following problems of the previous quiz to show the steps necessary to complete them.

Problem 1. $I = E/R$, $E = 150$ V, $R = 25$ kΩ, $I =$ ______mA or _______A.

$$I = \frac{150V}{25\ k\Omega} = \frac{150\ V}{25 \times 10^3}$$

$$= \frac{150}{25 \times 10^3}$$

$$= \frac{150 \times 10^{-3}}{25}$$

$$= 6 \times 10^{-3}\ A = 6\ mA \text{ or } .006\ A$$

Problem 3. $P = I^2 R$, $I = 3$ mA, $R = 7$ kΩ, $P =$ _______mW or ________W

$$P = (3\ mA)^2 \times 7\ k\Omega = (3 \times 10^{-3})^2 \times 7 \times 10^3$$

$$= 3^2 \times (10^{-3})^2 \times 7 \times 10^3$$

$$= 9 \times 10^{-6} \times 7 \times 10^3$$

$$= (9 \times 7) \times 10^{-6+3}$$

$$= 63 \times 10^{-3} = 63\ mW \text{ or } .063W$$

Problem 4. $X_C = \frac{.159}{fC}$, $f = 53$ Hz, $C = 15$ μF, $X_C =$ ________kΩ or ______Ω.

$$X_C = \frac{.159}{53 \times 15 \times 10^{-6}} = \frac{159 \times 10^{-3}}{53 \times 15 \times 10^{-6}}$$ (Changed .159 to $159 \times 10^{-3}$)

$$= \frac{159 \times 10^{-3}}{795 \times 10^{-6}}$$

$$= \frac{159 \times 10^{-3} \times 10^6}{795}$$

$$= .2 \times 10^{-3+6}$$

$$= .2 \times 10^3 = .2\ k\Omega \text{ or } 200\ \Omega\ .$$

**ANSWERS TO MASTER QUIZ 11.**

1. 6 mA, .006A
2. 2 μs, .002 ms
3. 63 mW, .063 W
4. .2 kΩ, 200Ω
5. 4250 mV, 4.25 V
6. 12 k meters, 12,000 meters

Problem 6. $\lambda = \frac{V}{f}$, V = 300 x $10^6$ meters/second, f = 25 kHz, $\lambda$ = ___k meters or ___ meters

$$= \frac{300 \times 10^6 \text{ meters/second}}{25 \text{ kHz}} = \frac{300 \times 10^6}{25 \times 10^3}$$

$$= \frac{300 \times 10^6 \times 10^{-3}}{25}$$

$$= 12 \times 10^{6 + (-3)}$$

$$= 12 \times 10^3 = 12 \text{ k meters or } 12000 \text{ meters.}$$

Solving electrical formulas uses your knowledge of operations with powers of ten and common prefixes used with units of measure. An adequate understanding of both areas are necessary in becoming a technician.

---

SUB QUIZ 11. Solve the formulas for the indicated values.

1. $X_L = 6.28 fL$, f = 10 kHz, L= 4 mH $X_L$ = ______Ω or ______kΩ.
2. $P = E^2/R$, E = 15 kV, R = 10 MΩ, P = ______W or ________mW
3. $R = \sqrt{Z^2 - X^2}$, Z = .01 kΩ, X = 8Ω, R = ______Ω or________kΩ.
4. R = E/I, E = 96 V, I = 8 mA, R = ______kΩ or ________Ω.
5. $I = \sqrt{P/R}$, P = 400 mW, R = 100 kΩ, I = ________mA or ________A.
6. $f = \frac{.159}{C \times X_C}$, C = 10 pF, $X_C$ = 159 kΩ, f = ______MHz or ______kHz.

Check your answers on the next even-numbered page.

If you missed an answer, review previous paragraphs. If your answers are correct, you are ready to study equations so continue reading.

---

## EQUATIONS

In order to solve electronics problems you must be able to use formulas and solve equations. An equation is a mathematical statement that two quantities are equal. $6 + 5 = 8 + 3$ is an equation because the quantity on the left side of the equal sign is equal to the quantity on the right side.

An equation is a precision-balanced scale. It is balanced when you begin working with it, and you must maintain that balance when solving the equation. When solving equations you can add, subtract multiply, divide, raise to powers, and extract roots -- as long as you perform the same operation to both sides of the equation!

To solve equations, we use certain rules and facts that are always true. These rules must be applied to both sides of the equation to keep the two sides equal. The rules are:

1. You can add the same number to both sides.
2. You can subtract the same number from both sides.
3. You can multiply both sides by the same number.
4. You can divide both sides by the same number.
5. Two terms equal to a third term are equal to each other.
6. You can raise both sides to the same power.
7. You can take the same root of both sides.

ANSWERS TO SUB QUIZ 11.

1. $251.2\,\Omega$ , $.2512\ k\Omega$
2. 22.5 W, 22,500 mW
3. $6\,\Omega$ , $.006\ k\Omega$
4. $12\ k\Omega$ , $12{,}000\,\Omega$
5. 2 mA, .002A
6. .1MHz, 100 kHz

Equations are usually solved by transposition using the rules stated above. Transposition is the operation of rearranging an equation to leave the letter representing the unknown value on one side of the equal sign and all other terms on the other side of the equal sign. In other words, terms must be moved from one side of the equation to the other in order to isolate the unknown value.

---

MASTER QUIZ 12. Solve for the unknown value.

1. $X + 10 = 18$
2. $3X - 12 = 24$
3. $7X - X = 49 - X$
4. $6X + 10 = 10X - 10$
5. $\frac{3X}{4} = 27$
6. $-8X + 40 = -2X - 10$

Check your answers on the next even-numbered page. If you missed less than two, proceed to MASTER QUIZ 13. If you missed two or more, continue reading.

---

As was stated earlier, rules are used to solve equations. Let's look at an application of each of the above rules to understand their usage.

1. Add the same number to both sides.

$X - 5 = 12$

$X - 5 + 5 = 12 + 5$

$X = 17$

By adding the same number (5) to both sides, we isolate the unknown (X).

2. Subtract the same number from both sides.

$Z + 10 = 12$ By subtracting the same number (10)

$Z + 10 - 10 = 12 - 10$ from both sides, the unknown ( Z)

$Z = 2$ is isolated.

3. Multiply both sides by the same number.

$\frac{X}{5} = 12$ Here both sides of the equation were multiplied

by $\frac{5}{1}$ in order to isolate the

$\frac{X}{5} \times \frac{5}{1} = 12 \times \frac{5}{1}$ unknown value (X).

$X = 60$

4. Divide both sides by the same number.

$5X = 85$ Both sides of the equation were divided by the

$\frac{5X}{5} = \frac{85}{5}$ same number (5) to find the unknown value (X).

$X = 17$

5. Terms equal to a third term are equal to each other.

$Y = M$ and $X = M$

therefore $X = Y$ because X and Y are both equal to M.

6. Raising both sides to the same power.

$\sqrt{M} = 3$ By squaring both sides of the equation, the

$(\sqrt{M})^2 = 3^2$ radical (square root sign) is removed from the

$M = 9$ unknown and the equation is solved.

7. Taking the same root of both sides.

$X^2 = 36$ By taking the square root of both sides, the

$\sqrt{X^2} = \sqrt{36}$ value of X is found.

$X = 6$

**ANSWERS TO MASTER QUIZ 12.**

1. $X = 8$
2. $X = 12$
3. $X = 7$
4. $X = 5$
5. $X = 36$
6. $X = 8.3$

You should notice in the above rules that both sides of the equation were treated the same. Remember, an equation is a balanced scale. In order to keep it balanced, the same operation must be performed on both sides of the equal sign.

Study the following example:

Example 1. $X - 10 = 15$ Solve for X.

$X - 10 + 10 = 15 + 10$

$X = 25$

In order to solve this equation, you must isolate the unknown value (X) on one side of the equal sign. This involves adding 10 to both sides of the equation. In other words, the 10 is moved by performing the inverse operation on it.

In terms of inverse operations, addition and subtraction are inverse operations, and squaring and square rooting are inverse operations.

Example 2. $Z + 4 = 6$ Solve for Z.

$Z + 4 - 4 = 6 - 4$ (Rule 2)

$Z = 2$

Example 3. $\frac{X}{7} = 3$ Solve for X.

$\frac{X}{7} \times \frac{7}{1} = 3 \times \frac{7}{1}$ (Rule 3)

$X = 21$

Example 4. $9X = 108$ Solve for X.

$\frac{9X}{9} = \frac{108}{9}$ (Rule 4)

$X = 12$

Example 5. $14 = X + 7$ Solve for X.

$14 - 7 = X + 7 - 7$ (Rule 2)

$7 = X$

Example 6. $Y + 3 = 2$ Solve for Y.

$Y + 3 - 3 = 2 - 3$ (Rule 2)

$Y = -1$

Every equation can be checked by substituting the value of the unknown into the original equation. Note the following example.

Example 7. $\frac{X}{12} = 6$ Solve for X.

$\frac{X}{12} \times \frac{12}{1} = 6 \times \frac{12}{1}$

$X = 72$

Check: $\frac{72}{12} = 6$

$6 = 6$

Up to this point the equations have been solved in just one step. Of course, this will not always be the case. But, any equation can be solved using the rules for each step in the solution.

Example 8. $13X - 8 = 11 - 6X$ Solve for X.

$13X - 8 + 6X = 11 - 6X + 6X$ (Rule 1)

$19X - 8 = 11$

$19X - 8 + 8 = 11 + 8$ (Rule 1)

$19X = 19$

$\frac{19X}{19} = \frac{19}{19}$ (Rule 4)

$X = 1$

Check: $13X - 8 = 11 - 6X$

$13(1) - 8 = 11 - 6(1)$

$13 - 8 = 11 - 6$

$5 = 5$

For problems involving more than one step, do the steps in the following order:

1. Combine any terms that have the same units or unknowns.
2. Use your rules to put all terms with the unknown on one side.
3. Use the rules to put all terms without the unknown on the other side.
4. Combine terms that have the same units or unknowns.
5. Use your rules to complete the problem.

Example 9. $7X - 8 + 4 = 3X + 9 + 15$ Solve for X.

$7X - 4 = 3X + 24$ (Combine like terms.)

$7X - 4 - 3X = 3X + 24 - 3X$ (Rule 2)

$4X - 4 = 24$

$4X - 4 + 4 = 24 + 4$ (Rule 1)

$4X = 28$

$\frac{4X}{4} = \frac{28}{4}$ (Rule 4)

$X = 7$

Check: $7X - 8 + 4 = 3X + 9 + 15$

$7(7) - 8 + 4 = 3(7) + 9 + 15$

$49 - 8 + 4 = 21 + 9 + 15$

$45 = 45$

Example 10. $\frac{7X}{10} = 14$ Solve for X

$\frac{7X}{10} \times \frac{10}{1} = 14 \times \frac{10}{1}$ (Rule 3)

$7X = 140$

$\frac{7X}{7} = \frac{140}{7}$ (Rule 4)

$X = 20$

Check: $\frac{7X}{10} = 14$

$\frac{7(20)}{10} = 14$

$\frac{140}{10} = 14$

$14 = 14$

By the application of the rules of transposition, the solution of equations becomes a series of easy steps. Remember, once you have solved for the unknown, you can also check yourself by substituting your answer for the unknown in the original problem.

---

SUB QUIZ 12. Solve for the unknown value.

1. $3X - 6 = 9$
2. $\frac{4X}{7} + 3 = 15$
3. $5X - 4 + 2X = 2X - 4 - 20$
4. $X^2 - 3 = 97$
5. $4X - 8 = 2X + 10$
6. $-2X + 9 + 1 - 4 = -3X + 19$

Check your answers on the next even-numbered page. If you missed an answer review preceding paragraphs. If your answers are correct, take MASTER QUIZ 13.

---

MASTER QUIZ 13. Solve for unknown value.

1. $\frac{2X}{3} + 6 = \frac{3}{4}$
2. $\frac{X}{5} - \frac{3}{10} = \frac{X}{3}$
3. $6\,(X - 7) = 30$
4. $2X^2 - 7 = X^2 + 9$
5. $\frac{5(X + 6)}{7} = 40$
6. $4X - 3(X-7) = 21$

Check your answers on the next even-numbered page. If you misses less than two, take MASTER QUIZ 14. If you missed two or more continue reading.

---

When working electronic equations, you may run into problems that contain many groups of fractions such as this one: $\frac{4X}{3} - \frac{3}{2} = \frac{X}{3} - 1$ There are a few general rules to solving all equations; and one of them is that to simplify equations, all fractions must be cleared.

### ANSWERS TO SUB QUIZ 12.

1. $X = 5$
2. $X = 21$
3. $X = -4$
4. $X = 10$
5. $X = 9$
6. $X = 13$

### ANSWERS TO MASTER QUIZ 13.

1. $X = 7.9$
2. $X = -2.25$
3. $X = 12$
4. $X = 4$
5. $X = 50$
6. $X = 0$

To clear fractions, you must multiply every term by the LOWEST COMMON DENOMINATOR. The LCD is a number that all of the divisors can divide into evenly. By multiplying by the LCD, all denominators are cancelled; therefore, there are no fractions left in the equation.

Observe, once more, the previous equation given: $\frac{4Y}{3} - \frac{3}{2} = \frac{Y}{3} - 1$. The denominators in the three fractions are 3, 2, and 3 again. In order to clear fractions here, 6 would be the LCD because every denominator divides evenly into 6. Let's follow the solution below:

$\frac{(6)4Y}{3} - \frac{(6)3}{2} = \frac{(6)Y}{3} - (6)1$ (Multiply by 6)

$2(4Y) - 3(3) = 2Y - 6$ (Divide each denominator into 6)

$8Y - 9 = 2Y - 6$

$8Y - 2Y - 9 = -6$ (Rule 2)

$8Y - 2Y = -6 + 9$ (Rule 1)

$6Y = 3$

$Y = .5$ (Rule 4)

Example 2. $\frac{2X}{3} - 6 = \frac{3}{4}$

$\frac{(12)2X}{3} - (12)6 = \frac{(12)3}{4}$ (Multiply by 12 -- the LCD)

$4(2X) - 72 = 3(3)$

$8X - 72 = 9$

$8X = 9 + 72$ (Rule 1)

$8X = 81$

$X = 10.125$ (Rule 4)

Example 3. $\frac{4X}{5} - 3 = \frac{X}{3} - \frac{7}{15}$

$\frac{(15)4X}{5} - (15)3 = \frac{(15)X}{3} - \frac{(15)7}{15}$ (Multiply by 15 -- the LCD)

$3(4X) - 45 = 5X - 7$

$12X - 45 = 5X - 7$

$12X - 5X - 45 = -7$ (Rule 2)

$7X - 45 = -7$

$7X = -7 + 45$ (Rule 1)

$7X = 38$

$X = 5.375$ (Rule 4)

Example 4. $\frac{5}{2Y} + \frac{1}{2} = \frac{7Y - 1}{5Y}$

$\frac{(10Y)5}{2Y} + \frac{(10Y)1}{2} = \frac{(10Y)(7Y-1)}{5Y}$ (Multiply by 10Y ---The LCD)

$5(5) + 5Y(1) = 2(7Y-1)$

$25 + 5Y = 14Y - 2$

$25 = 14Y - 5Y - 2$ (Rule 2)

$25 = 9Y - 2$

Example 4 (Cont'd) $25 + 2 = 9Y$ (Rule 1)

$27 = 9Y$

$3 = Y$ (Rule 4)

In the above example, the unknown (Y) was part of the denominator, and so it must also be part of the LCD. Since 2 and 5 both divide into 10 evenly, 10Y is the LCD. Every term was multiplied by 10Y.

Refer to Example 4 again. In the second step of that solution you will see this: 2(7Y-1). Another important aid to solving equations is to get rid of parenthesis immediately. This is accomplished easily by multiplying each term inside the parenthesis by the value outside the parenthesis. In this example, 7Y is multiplied by 2 and -1 is multiplied by 2. Therefore, $2(7Y-1) = 2(7Y) + 2(-1) = 14Y - 2$.

Example 5 also shows the solution of a problem were the unknown is in the denominator.

Example 5. $\frac{5}{6} - \frac{1}{3X} = 0$

$\frac{(6X)5}{6} - \frac{(6X)1}{3X} = (6X)0$ (LCD is 6X)

$5X - 2 = 0$

$5X = 2$ (Rule 1)

$X = .4$ (Rule 4)

Again note that the unknown (X) is part of the denominator. Therefore, since 3 and 6 divide into 6 evenly, the LCD is 6X. IMPORTANT. Every term of the equation must be multiplied by the LCD in order to keep the equation balanced.

Example 6. $3(4-X) - 2(X-6) = 0$

$3(4) + 3(-X) - 2(X) + (-2)(-6) = 0$

$12 - 3X - 2X + 12 = 0$

$12 - 5X + 12 = 0$

$24 - 5X = 0$

$24 = 5X$

$4.8 = X$

Example 7. $3(X^2 + 5) = 2(X^2 + 20)$

$3(X^2) + 3(5) = 2(X^2) + 2(20)$

$3X^2 + 15 = 2X^2 + 40$

$3X^2 - 2X^2 = 40 - 15$ (Rule 2)

$X^2 = 25$

$X = 5$ (Rule 7)

Example 8. $\frac{8(X-2)}{3} = 16$

$8(X-2) = 16(3)$ (Multiply both sides by 3 — the LCD)

$8(X) + 8(-2) = 48$

$8X - 16 = 48$

$8X = 48 + 16$ (Rule 1)

$8X = 64$

$X = 8$ (Rule 4)

As you can imagine, equations can get to be pretty difficult to solve - especially when the solution involves many steps. A good step approach to equation solving can be summarized as follows:

Step 1. Clear fractions (if there are any) by multiplying each term by the LCD.

Step 2. Get rid of parenthesis by multiplying each term inside the parenthesis by the value outside the parenthesis.

Step 3. Use the seven rules as presented earlier to complete the solution for the unknown value.

If you follow this procedure, solving equations will be much easier.

---

SUB QUIZ 13. Solve for the unknown value.

1. $2(2X-3) + 6 = 4(X+1) + 2X$
2. $\frac{X}{4} + \frac{1}{8} = \frac{3X}{2} - 5$
3. $X^2 + 6 = 2(X^2 - 5)$
4. $\frac{5(X+7)}{6} = \frac{10}{3}$
5. $3\,(4-2X) - 2\,(X-6) = 0$
6. $\frac{4}{3X} - \frac{2}{5} = 2$

Check your answers on the next even-numbered page. If you missed an answer, review preceding paragraphs. If your answers are correct, take MASTER QUIZ 14.

---

MASTER QUIZ 14. Rearrange the following formulas for the quantity requested.

1. $X_L = 2\pi fL$ Solve for f.
2. $X_C = \frac{.159}{fC}$ Solve for f.
3. $P = I^2R$ Solve for I.
4. $I = \frac{E}{R}$ Solve for E.
5. $Z = \sqrt{R^2 + X^2}$ Solve for R.
6. $\frac{A}{B} = \frac{C}{D}$ Solve for A.

Check your answers on the next even-numbered page. If you missed less than two, begin reading with first paragraph after SUB QUIZ 14. If you missed two or more, continue reading.

---

Your work in electronics will involve many formulas that contain more than one unknown quantity. You must be able to rearrange these formulas to find any quantity in terms of other quantities involved. This type of equation is called a LITERAL EQUATION.

The number of possible arrangements of a formula is equal to the number of unknown quantities in that formula. Therefore, if there are four unknowns in a formula, that formula can be written four different ways. For example, the formula $X_L = 2\pi fL$ has a total of three unknowns. Besides being written in terms of $X_L$, the formula can also be written in terms of f or L.

In the unknown quantity $X_L$ the L is below the line and is called a subscript. A subscript is used to more narrowly define the unknown quantity. For instance, in $X_L$ the X means reactance and the L means inductance, so $X_L$ is inductive reactance. The quantity $X_C$ means capacitive reactance as X means reactance and C means capacitance.

In order to solve a literal equation you use the same rules as for the previous equations. Remember that the letters stand for numbers and are treated just like any other numbers.

The two most important things to remember are as follows:

1. Whatever process you apply to one side of an equation must also be applied to the other side.
2. Apply whatever rule is necessary to isolate the letter desired on one side of the equation.

**ANSWERS TO SUB QUIZ 13**

1. $X = =2$
2. $X = 4.1$
3. $X = 4$
4. $X = -3$
5. $X = 3$
6. $X = 5.6$

**ANSWERS TO MASTER QUIZ 14**

1. $f = \frac{X_L}{2 \pi L}$
2. $f = \frac{.159}{X_C C}$
3. $I = \sqrt{\frac{P}{R}}$
4. $E = IR$
5. $R = \sqrt{Z^2 - X^2}$
6. $A = \frac{BC}{D}$

Given the formula $I = \frac{E}{R}$ let's rearrange the terms to solve for E.

Example 1. $I = \frac{E}{R}$ Solve for E.

$(R)I = \frac{(R)E}{R}$ (Rule 3. Multiply both sides by R)

$RI = E$

Now this equation can be used to find E when numerical values are given for I and R. The values are substituted into the equation in the proper place and solved. Now solve the same equation for R.

Example 2. $I = \frac{E}{R}$ Solve for R.

$(R)I = \frac{(R)E}{R}$ (Rule 3)

$RI = E$

$\frac{RI}{I} = \frac{E}{I}$ (Rule 4)

$R = \frac{E}{I}$

Remember that fractions should be eliminated as soon as possible when solving equations. Isolating R took two steps as you can see. First fractions were eliminated by multiplication; then division was used to move the I to the right side of the equation.

The formula just solved, $I = \frac{E}{R}$, is not only the simplest formula used in electronics; but it is also the most commonly used. When given any two of the three quantities, you can easily solve for the third.

This formula can also be converted from one form to another by what is called the "rule of thumb" method. Look at figure 4 below. If you put your thumb over the unknown quantity, the mathematical process to follow is clearly indicated. For example, if you want to solve the equation in terms of E, cover the E with your thumb. Thus the mathematical process for finding E is I x R. Covering I would produce the process $\frac{E}{R}$. If R is the unknown, cover the R and you get $\frac{E}{I}$.

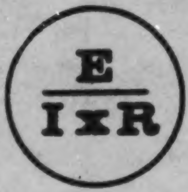


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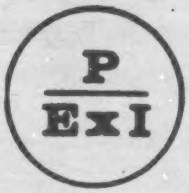
Figure 4.

The "rule of thumb" method is the quickest way to solve this particular equation, and may be used in your problems. However, you should be able to follow the method of solving equations using the rules.

Another frequently used formula in electronics is $P = EI$. As you may already suspect, the rule of thumb method can also be used with this equation as shown in Figure 5. Cover one of the unknowns with your thumb and the mathematical process to use to find that unknown will be indicated.



REP 4-327

Figure 5.

Of course, $I = \frac{E}{R}$ and $P = EI$ are simple formulas compared to a few you may encounter in later studies. But no matter how complex the formulas may appear, they can all be converted from one unknown to another by means of the seven rules previously presented. Study the following examples and note the rules used.

Example 3. $X_L = \frac{fL}{.159}$ Solve for f.

$$(.159)X_L = \frac{(.159)fL}{.159} \quad \text{(Rule 3)}$$

$$.159X_L = fL$$

$$\frac{.159X_L}{L} = \frac{fL}{L} \quad \text{(Rule 4)}$$

$$\frac{.159X_L}{L} = f$$

Example 4. $F = \frac{Q_1 \times Q_2}{d^2}$ Solve for $Q_1$

$$(d^2)F = \frac{(d^2)(Q_1 \times Q_2)}{d^2} \quad \text{(Rule 3)}$$

$$d^2F = Q_1 \times Q_2$$

$$\frac{d^2 F}{Q_2} = \frac{Q_1 Q_2}{Q_2} \quad \text{(Rule 4)}$$

$$\frac{d^2 F}{Q_2} = Q_1$$

Example 5. $E_a = \sqrt{E_R{}^2 + E_C{}^2}$ Solve for $E_R$.

$$E_a{}^2 = (\sqrt{E_R{}^2 + E_C{}^2})^2 \quad \text{(Rule 6)}$$

$$E_a{}^2 = E_R{}^2 + E_C{}^2$$

$$E_a{}^2 - E_C{}^2 = E_R{}^2 + E_C{}^2 - E_C{}^2 \quad \text{(Rule 2)}$$

$$E_a{}^2 - E_C{}^2 = E_R{}^2$$

$$\sqrt{E_a{}^2 - E_C{}^2} = \sqrt{E_R{}^2} \quad \text{(Rule 7)}$$

$$\sqrt{E_a{}^2 - E_C{}^2} = E_R$$

Example 6. $\frac{N_p}{N_s} = \frac{E_p}{E_s}$ Solve for $E_s$.

$$\frac{(E_s)N_p}{N_s} = \frac{E_p(E_s)}{E_s} \quad \text{(Rule 3)}$$

$$\frac{E_s N_p}{N_s} = E_p$$

$$\frac{(N_s)E_s N_p}{N_s} = (N_s)E_p \quad \text{(Rule 3)}$$

$$E_s N_p = N_s E_p$$

$$\frac{E_s N_p}{N_p} = \frac{N_s E_p}{N_p} \quad \text{(Rule 4)}$$

$$E_s = \frac{N_s E_p}{N_p}$$

**SECOND METHOD:**

$$\frac{N_p}{N_s} = \frac{E_p}{E_s}$$

$$N_p E_s = E_p N_s$$

$$E_s = \frac{E_p N_s}{N_p}$$

In Example 6 a second method called CROSS MULTIPLICATION was shown in solving for the unknown. Cross Multiplication is the multiplying of the numerator on one side of the equal sign by the denominator on the other side of the equal sign. This is indicated by the arrows in the problem. Two ratios can be easily solved using this method. Cross multiplication gets rid of fractions quickly.

---

SUB QUIZ 14. Rearrange the following formulas for the unknown as specified.

1. $P = \frac{E^2}{R}$ Solve for E.
2. $F = \frac{M_1 \times M_2}{d^2}$ Solve for d.
3. $X_C = \frac{.159}{fC}$ Solve for C.
4. $\frac{I_s}{I_p} = \frac{E_p}{E_s}$ Solve for $I_p$.
5. $C = \frac{Ak}{d}$ Solve for A
6. $X = \sqrt{Z^2 - R^2}$ Solve for Z.

Check your answers on the next even-numbered page. If you missed an answer, review preceding paragraphs. If your answers are correct, continue reading.

---

In direct current circuits, the electronic technician is concerned with three values: voltage, current, and resistance. Earlier you worked with the formula $I = \frac{E}{R}$ at which time it was stated that this was the basic formula in electricity.

George S. Ohm, a German scientist, developed this formula and so it was appropriately entitled Ohm's Law. He stated: "The current in a circuit is directly proportioned to the applied voltage and inversely proportional to the resistance." Hence $I = \frac{E}{R}$ and:

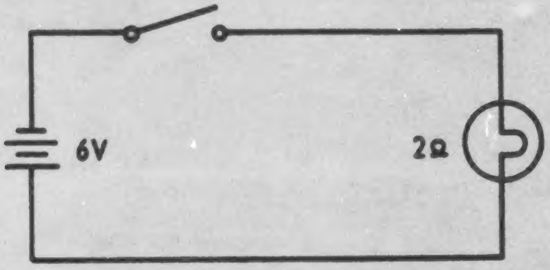
E = Voltage ---- measured in volts (V).

I = Current ---- measured in amperes (A).

R = Resistance - measured in ohms ($\Omega$).

If you know any two of the values, you can always compute the third. You can convert $I = \frac{E}{R}$ into formulas for E and R using rules or you can use the "rule of thumb" discussed in preceding paragraph.

Now let's see how Ohm's Law is applied to a simple electrical circuit. Assume the circuit shown in Figure 6 is a railroad lantern. It consists of a 6 volt battery, a switch, and a lamp with a resistance of 2 ohms. The problem is to find the current when the switch is closed.



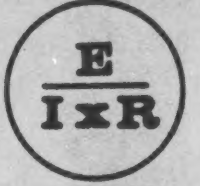
REP4-328

Figure 6.

According to Ohm's Law, current (I) is equal to voltage (E) divided by resistance (R) or $I = \frac{E}{R}$;

$$I = \frac{E}{R} \text{ or Amps} = \frac{\text{volts}}{\text{ohms}}$$

$$I = \frac{6V}{2\Omega} = 3A$$



Let's assume that in the above circuit, that the resistance of the lamp is 5$\Omega$ and that the current is 2A. The value you don't know is voltage (E). The formula for voltage is E = I x R.

$$E = I \times R \text{ or volts} = \text{Amps} \times \text{Ohms}$$

$$E = 2A \times 5\Omega$$

$$E = 10V$$

**ANSWERS TO SUB QUIZ 14**

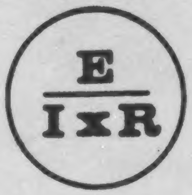
1. $E = \sqrt{PR}$
2. $d = \frac{M_1 \times M_2}{f}$
3. $C = \frac{.159}{fX_C}$
4. $I_p = \frac{I_s E_s}{E_p}$
5. $A = \frac{dC}{K}$
6. $Z = \sqrt{R^2 + X^2}$

Let's go one step further and assume the battery's voltage is 12V and the current is 3A in the circuit. Then the formula for finding the unknown value of resistance is $R = \frac{E}{I}$

$R = \frac{E}{I}$ or $\text{ohms} = \frac{\text{volts}}{\text{Amps}}$

$R = \frac{12V}{3A}$

$R = 4\Omega$



REP 4-326

Therefore, the three forms of Ohm's Law are:

Resistance: $R = \frac{E}{I}$ the answer is expressed in ohms.

Current: $I = \frac{E}{R}$ the answer is expressed in amperes.

Voltage: $E = IR$ the answer is expressed in volts.

Each of these comes from the "Rule of Thumb".

As a technician, not only must you be able to solve Ohm's Law but you should also be able to state the effects when one or two values change. For example, when voltage is increased in a circuit and the resistance is held constant, how will the current change? The correct answer is that current will increase.

You could look at the formula $I = \frac{E}{R}$ and see that if R is constant and E increases, then I would have to increase. Thus more current is a result of more voltage. This is because current and voltage are directly proportional — an increase in one means an increase in the other and a decrease in one means a decrease in the other, providing resistance stays constant.

If voltage is kept constant and resistance decreases, then current would increase again. By looking at the formula $I = \frac{E}{R}$, you should be able to see this. Therefore, current and resistance are inversely proportional -- they react oppositely to each other when voltage remains constant.

---

SUB QUIZ 15. Solve:

1. R = 10Ω , E = 50V, I = ______
2. E = 100V, I = 10A, R = ________
3. R = 20 kΩ , I = 3mA, E = ______
4. E decreases, R constant, I ______
5. E doubles, R doubles, I ________
6. R increases, E constant, I ______

Check your answers on the next even-numbered page. If you missed an answer, review preceding paragraphs. If your answers are correct, you have completed this program.

---

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

**ANSWERS TO SUB QUIZ 15.**

1. I = 5A
2. R = 10 Ω
3. 60 V
4. decreases
5. remains constant
6. decreases

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Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 4

## DIRECT CURRENT AND VOLTAGE

1 May 1974

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# ELECTRONIC PRINCIPLES

## MODULE 4

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

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| List of Resources | 2 |
| Digest | 3 |
| Adjunct Guide | 4 |
| Module Self Check | 11 |

Supersedes KEP-GP-4, 1 November 1973. Use previous edition until exhausted.

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## DIRECT CURRENT AND VOLTAGE

1. SCOPE. All of the effects of electricity can be explained by assuming the existance of a tiny particle called the electron. To direct and confine electrons requires the use of conductors and insulators. To furnish electrons requires the use of common sources of electromotive force. This module starts with the atom and finishes with electron flow and electrical pressure.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a group of statements, select the ones which describe a conductor and an insulator.

b. From a group of statements, select the one that describes the movement of free electrons within a conductor.

c. From a group of terms and symbols, select those which name the unit of measurement and symbol for electron flow.

d. From a group of statements, select the one which describes the pressure that causes the movement of free electrons within a conductor.

e. From a group of terms and symbols, select those which name the unit of measurement and the symbol for Electromotive Force.

f. From a group of statements, select five that describe common sources of Electromotive Force.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

## DIRECT CURRENT AND VOLTAGE

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

AUDIO-VISUALS

Television Lesson, Electrical Properties of Matter, TVK 30-101C

Television Lesson, Charged Bodies, TVK 30-101D

Television Lesson, Voltage, TVK 30-101E

Television Lesson, Current, TVK 30-101F

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

## DIRECT CURRENT AND VOLTAGE

### CONDUCTORS AND INSULATORS

The electrical conductivity of a material depends on its atomic structure, which determines if it is a conductor, a semi-conductor, or an insulator. A material which allows electrons to move from atom to atom is said to have free electrons and is a good conductor. A material which does not allow electrons to move from atom to atom is said to have no free electrons and is a good insulator.

Examples of good conductors are silver, copper, gold, and aluminum. Examples of good insulators are rubber, plastic, and glass. Silicon and germanium are examples of two common semi-conductors used in solid state devices.

### CURRENT AND VOLTAGE

Negatively (-) charged electrons revolve around the positively (+) charged protons of the atoms within a material. These electrons become an electric current when brought under the influence of an external force or charge. The movement of these electrons conforms to the law of charges, which states that LIKE CHARGES REPEL and UNLIKE CHARGES ATTRACT. When a material has a deficiency of electrons it has a positive charge. A surplus of electrons produces a negative charge.

When the charges are connected together through a conductor they exert a pressure on the free electrons of the conductor and cause them to move from the negative charge to the positive charge. This electron movement is known as CURRENT and is measured in amperes (A). The electrical symbol for current is the letter I.

In order to maintain current flow in a conductor, the positive and negative charges, or difference of potential, must be maintained. This pressure is known as electromotive force (EMF) and is measured in VOLTS (V). The electrical symbol for electromotive force is the letter E.

### SOURCES OF ELECTROMOTIVE FORCE

EMF may be produced by mechanical action (generator), chemical action (battery), thermoelectric effect (thermocouple), photoelectric (television camera), and piezoelectric (crystal microphone).

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## ADJUNCT GUIDE

## DIRECT CURRENT AND VOLTAGE

**INSTRUCTIONS:**

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

◆ ◆ ◆

A. Turn to Student Text Volume I and read paragraphs 3-1 thru 3-21. Return to this page and answer the following questions.

1. Identify the following by matching each with its proper number: (See figure)

a. __________ Nucleus

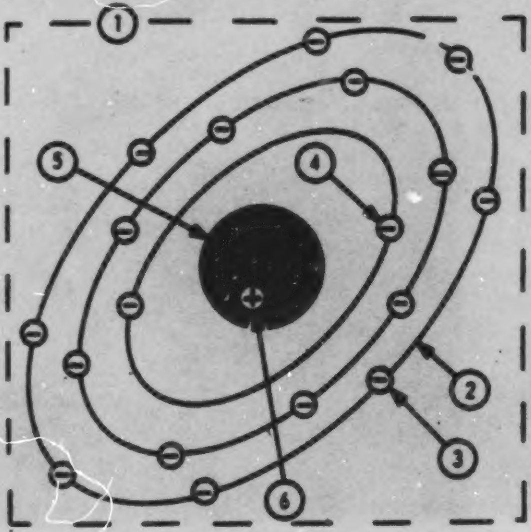
b. __________ Valence Electron

c. __________ Atom

d. __________ Proton

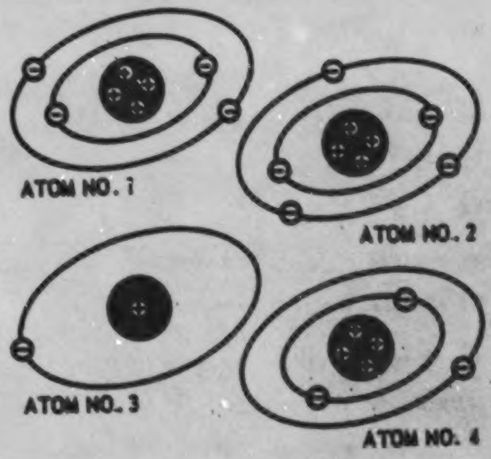
e. __________ Outer Orbit

f. __________ Electron in an Inner Orbit



2. Complete the chart by placing a check in the proper column:

| ATOM # | POSITIVE ION | NEGATIVE ION | NEUTRAL |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |



3. Complete the following chart by indicating the charge of each particle in an atom:

| PARTICLE | CHARGE |
|---|---|
| | |
| | |
| | |
| | |

4. Matter is defined as: ______________________________________________

______________________________________________________________

5. An ____________________ is the smallest particle of an element.

6. The two main particles found in the nucleus of an atom are the ____________________

and the ______________________________.

7. "Valence" refers to the ___________________________ behavior of an atom. The "Valence"

electrons in an atom are located ______________________________.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

◆ ◆ ◆

**ADJUNCT GUIDE**

**ANSWERS TO A:**

1. a) 5 d) 6
   b) 3 e) 2
   c) 1 f) 4

2. #1 neutral #3 neutral
   #2 negative ion #4 positive ion

3.

| | |
|---|---|
| Electron | Negative |
| Proton | Positive |
| Neutron | Neutral |

4. Anything that occupies space and has weight or mass.

5. Atom

6. Proton and Neutron

7. Chemical . . . in its outer ring.

If you missed ANY questions, review the material before you continue.

B. Turn to Student Text Volume I and read paragraphs 3-22 thru 3-32. Return to this page and answer the following questions.

1. A good conductor must have

   ____ a. an atomic structure without electrons.

   ____ b. a great number of atoms.

   ____ c. very few free electrons.

   ____ d. many free electrons.

2. A good insulator

   ____ a. opposes the movement of free electrons.

   ____ b. has many free electrons.

   ____ c. must have very few atoms.

   ____ d. has atomic structure with many free protons.

3. List four metals that could be used as conductors.

_______________ _______________

_______________ _______________

4. List six materials that could be used as insulators:

_______________ _______________

_______________ _______________

_______________ _______________

5. Semiconductor material lies between the extremes of a good _______________ and a good __________ .

6. The two most common semiconductor materials are _______________ and _______________.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

C. Turn to Student Text Volume I and read paragraphs 3-33 thru 3-53. Return to this page and answer the following questions.

1. List the three possible electrical charge conditions an object can have.

_______________ _______________ _______________

2. A coulomb is:

_____ a. An atom containing an equal number of electrons and protons.
_____ b. The opposition a device offers to the flow of electrons.
_____ c. Unit of electrical charge.
_____ d. The force between two charged bodies.

3. An application of Coulomb's Law would be:

_____ a. As the distance between two charged bodies increases, the force between them decreases.
_____ b. As the distance between two charged bodies decreases, the force between them decreases.
_____ c. Like charges attract, while unlike charges repel.
_____ d. All of the above.

ANSWERS TO B:

1. d

2. a

3. silver gold

   copper aluminum

4. rubber glass

   plastic dry wood

   enamel mica

5. conductor, insulator.

6. silicon, germanium

If you missed ANY questions, review the material before you continue.

4. If the distance between two charged bodies is doubled, the total force would:

   ____ a. Be twice as large.

   ____ b. Be one-half as large.

   ____ c. Be one-fourth as large.

   ____ d. No change.

5. Bodies with like charges ________________________________________.

6. Bodies with unlike charges ________________________________________.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

* * *

D. Turn to Student Text Volume I and read paragraphs 3-54 thru 3-66. Return to this page and answer the following questions.

1. The three things necessary for current flow are:

   ________________ ________________ ________________

2. One (1) ampere of electrical current is defined as:

    _____a. The number of volts required to produce electron flow through 1 ohm of resistance.

    _____b. The speed which electrons attain while in motion through a conductor.

    _____c. The movement of 1 coulomb past a point in 1 second.

    _____d. One volt per second past a given point in a circuit.

3. In an external circuit, the direction of electron flow is from ____________________ to ______________________________.

4. The symbol for current is ______________________________.

5. The practical unit of current is the:

    _____a. Ampere.

    _____b. Electron.

    _____c. Coulomb.

    _____d. Volt.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

* * *

E. Turn to Student Text Volume I and read paragraphs 3-66 thru 3-71. Return to this page and answer the following questions.

1. A correct definition for an EMF would be:

    _____a. An opposition to the flow of electrons.

    _____b. The force between two neutral bodies.

    _____c. A difference of potential.

    _____d. The amount of current.

2. The symbol for voltage is ______________________________.

3. List five common sources of EMF.

    ______________________________ ______________________________

    ______________________________ ______________________________

    ______________________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

* * *

ADJUNCT GUIDE

ANSWERS TO C:

1. neutral negative positive
2. c
3. a
4. c
5. repel each other.
6. attract each other.

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. a potential difference
   a conductor
   continuity
2. c
3. negative . . . . . . . positive
4. I
5. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO E:

1. c
2. E
3. mechanical photoelectric
   chemical piezoelectric
   thermoelectric

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## DIRECT CURRENT AND VOLTAGE

QUESTIONS:

1. A good conductor is described as any material which has
   a. many free atoms.
   b. many free electrons.
   c. few free atoms.
   d. few free electrons.
2. A good insulator is described as any material which has
   a. many free atoms.
   b. many free electrons.
   c. few free atoms.
   d. few free electrons.
3. The symbol for electron flow is ____________________.
4. The unit of measurement for electron flow is ____________________.
5. The pressure that causes current flow is described as ____________________.
6. The unit of measurement for EMF is the ____________________.
7. The symbol for electromotive force is ____________________.
8. Name five methods that describe common sources of EMF.
   a. ____________________
   b. ____________________
   c. ____________________
   d. ____________________
   e. ____________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK

1. b.
2. d.
3. I
4. ampere
5. a difference of potential, EMF, or Voltage.
6. volt
7. E
8. a. chemical
    b. mechanical
    c. photoelectric
    d. piezoelectric
    e. thermoelectric

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-5

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 5

## RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

1 June 1974

7-5

Keesler Technical Training Center
Keesler Air Force Base, Mississippi

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

ATC-GP 3AQR3X020-X
KEP-GP-5
1 June 1974

# ELECTRONIC PRINCIPLES

## MODULE 5

## RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

| | Page |
|---|---|
| Overview | 1 |
| List of Resources | 2 |
| Digest | 3 |
| Adjunct Guide | 8 |
| Laboratory Exercise 5-1 | 15 |
| Module Self-Check | 19 |

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Supersedes KEP-GP-5, 1 November 1973. Use existing stock until exhausted.

# RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

1. SCOPE: Resistance is another aspect of electricity that must be considered when dealing with electronic circuits.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives;

a. From a group of statements, select the one that describes the opposition to the movement of free electrons within a conductor.

b. From a group of terms and symbols, select those which name the unit of measurement and the symbol for resistance.

c. From a group of resistor symbols, select the symbol for a fixed, tapped, and variable resistor.

d. Given five resistor pictorials, classify each resistor as carbon, fixed wire, slide tap, rheostat, or potentiometer.

e. From a group of schematic symbols, select the one that represents a:

(1) battery.

(2) fuse.

(3) conductor.

(4) lamp.

(5) switch.

f. Using a resistor color code chart, determine the assigned value of five composition resistors.

g. Given four schematics showing two, three, or four batteries connected together, select the schematic connected for maximum output voltage.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK OR GO TO LABORATORY EXERCISE 5-1.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK OR GO TO THE LABORATORY EXERCISE, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES.

DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

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LIST OF RESOURCES

## RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

AUDIO-VISUALS:

Television Lesson, Resistance, TVK 30-101G

Television Lesson, Basic Circuit Components and Symbols, TVK 30-101H

Television Lesson, Rheostats and Potentiometers, TVK 30-124

LABORATORY EXERCISE:

Resistor Color Code 5-1

---

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

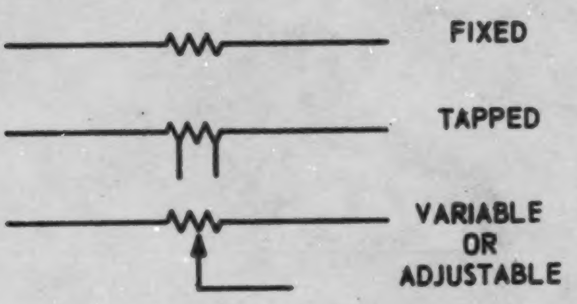
CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

## RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

### RESISTANCE AND RESISTORS

Resistance (R) is the opposition to current flow and the unit of measure is the ohm (Ω). When 1 volt causes 1 ampere of current to flow, the opposition is 1 ohm (1Ω).

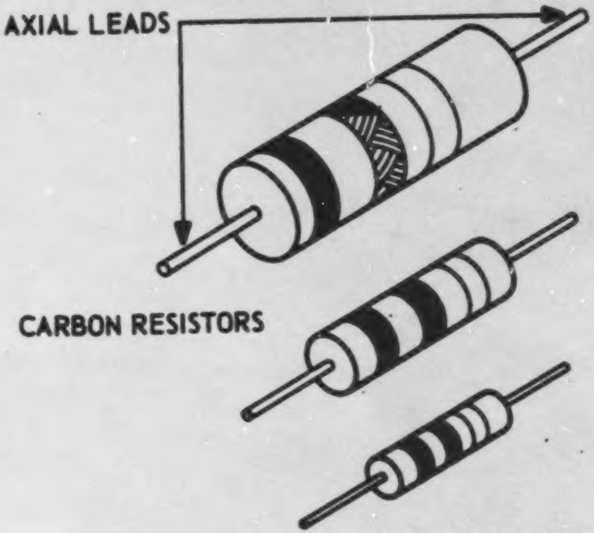
Resistors may be classified into three general types: fixed, tapped, and variable. Figure 1 shows the symbol for each.



REP4-488

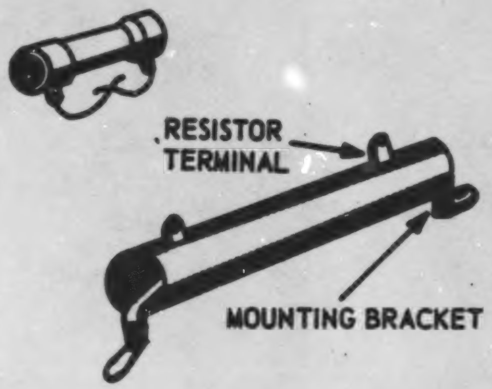
Figure 1

Carbon resistors are constructed from graphite and a binder. Wires are attached to the graphite and insulating material is molded around the graphite. See figure 2A. Fixed wire resistors are merely resistance wire wound on an insulating material. See figure 2B.



REP4-485

Figure 2A

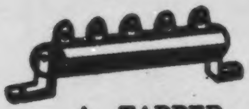


REP4-482

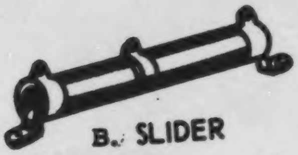
Figure 2B

## DIGEST

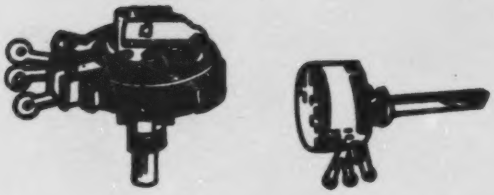
A tapped resistor is a wire-wound resistor with a tap or taps. See figure 3A. A slide tap is shown in figure 3B. A variable resistor could have carbon or resistance wire for the resistive element. See figure 3C and figure 3D. Notice that the potentiometer has three terminals while the rheostat has only two. A rheostat is used to get a change in current. A potentiometer is used to get a change in voltage.



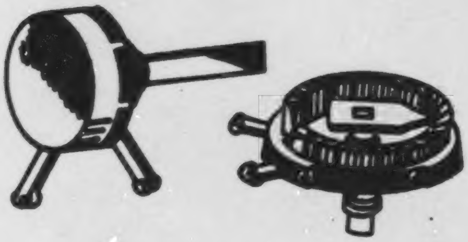
A. TAPPED



B. SLIDER



C. POTENTIOMETER



D. RHEOSTAT

Figure 3

## SCHEMATIC SYMBOLS

Figure 4 shows many schematic symbols you should become familiar with.

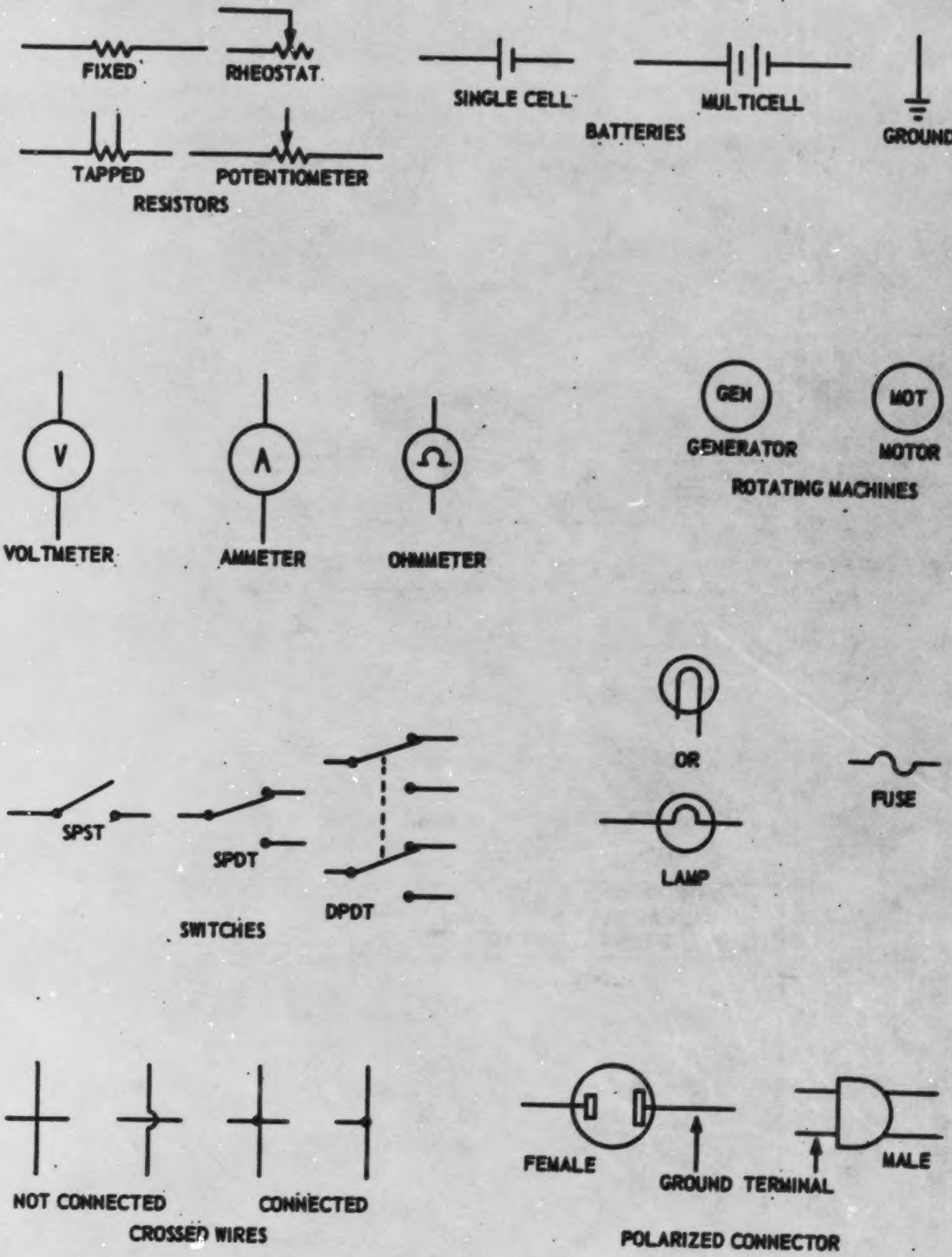
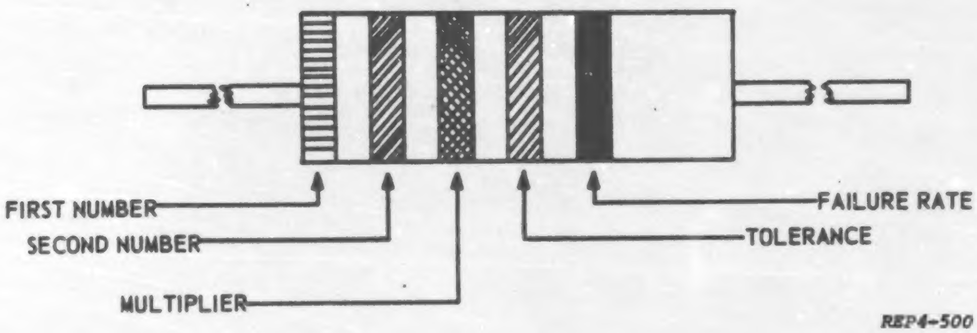

FIXED
RHEOSTAT
TAPPED
POTENTIOMETER
RESISTORS
SINGLE CELL
MULTICELL
BATTERIES
GROUND
V
VOLTMETER
A
AMMETER
OHMMETER
GEN
GENERATOR
MOT
MOTOR
ROTATING MACHINES
SPST
SPDT
DPDT
SWITCHES
OR
LAMP
FUSE
NOT CONNECTED
CONNECTED
CROSSED WIRES
FEMALE
GROUND TERMINAL
MALE
POLARIZED CONNECTOR

Figure 4

## DIGEST

## COLOR CODE

Most resistors will be color coded. The code type covered here is the END-TO-CENTER band system. Three bands of color are used to indicate the value of the tolerance. When not used, the tolerance is 20%. The fifth band, when used, indicates the failure rate. See figure 5.



REP4-500

### COLOR CODES FOR PART IDENTIFICATION MARKING

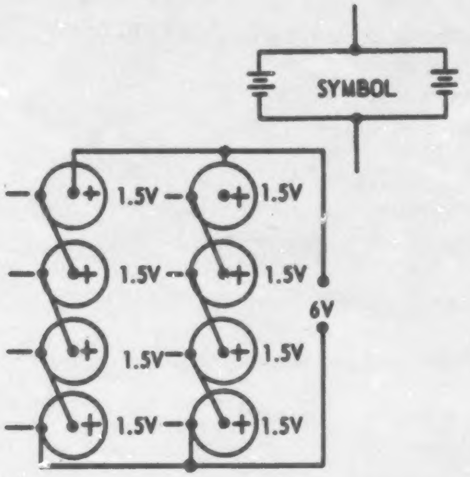
| COLOR | PART | SIGNIFICANT FIGURES OF ELECTRICAL VALUE | | | TOLERANCE | FAILURE RATE PER 1000 HRS |
|---|---|---|---|---|---|---|
| | | 1st Number | 2nd Number | Multiplier | | |
| Black | Capacitor | 0 | 0 | 1 | ±20% | L 5% |
| Brown | --- | 1 | 1 | 10 | ± 1% | M 1% |
| Red | --- | 2 | 2 | 100 | ± 2% | P 0.1% |
| Orange | --- | 3 | 3 | 1000 | --- | R 0.01% |
| Yellow | --- | 4 | 4 | 10000 | --- | S 0.001% |
| Green | Diode | 5 | 5 | 100000 | --- | T 0.0001% |
| Blue | --- | 6 | 6 | 1000000 | --- | |
| Violet | --- | 7 | 7 | 10000000 | --- | |
| Gray | --- | 8 | 8 | | --- | |
| White | --- | 9 | 9 | | --- | |
| Gold | --- | - | - | 0.1 | ± 5% | |
| Silver | Coil | - | - | 0.01 | ±10% | |

Figure 5

## BATTERY CELLS IN SERIES AND PARALLEL

When a battery of cells is used as a source of EMF, the desired output voltage and current carrying ability is determined by how the cells are connected together. Voltages of all cells in series will add together. When connected in parallel, the output is the same, but the current available will be doubled when two cells are in parallel. Figure 6 shows a series parallel hookup of eight 1.5-volt cells to get 6 volts out.

> NOTICE: For the series connection, the negative terminal of one cell is connected to the positive terminal on the next cell. The voltage will add up to 6 volts. The parallel connection is made by connecting the two positive terminals together and the two negative terminals together for the two series sets. The parallel connection will double the available current value.



REP4-499

Figure 6

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ADJUNCT GUIDE

## RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

INSTRUCTIONS:

Study the reference materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

* * * * * * *

A. Turn to student text volume 1 and read paragraphs 3-72 through 3-82. Return to this page and answer the following questions.

1. Resistance is defined as:

. . . a. The electrostatic charge between two bodies.

. . . b. One coulomb per second past a given point.

. . . c. Opposition to the flow of electric current.

. . . d. The potential difference between two points.

2. The practical unit of resistance is the . . . . . . . . . .

3. The symbol for resistance is . . . . . . . . . .

4. Factors that determine the resistance of a conductor are:

. . . a. Length, diameter, and temperature.

. . . b. Length, diameter, temperature, and the material used in the conductor.

. . . c. Length, diameter, temperature, and the porcelain base.

. . . d. Length, diameter, temperature, and the cross-sectional area.

5. Which of the following materials are commonly used in resistors?

. . . a. Carbon and glass.

. . . b. Metal film and ceramic.

. . . c. Wire and mica.

. . . d. Wire and carbon.

6. The resistance of a conductor is directly proportional to its . . . . . . . . . . . . . .

7. The resistance of a conductor is inversely proportional to its . . . . . . . . . . . . .

8. The opposition to current flow is called . . . . . . . . . . . . . . . . . . . . . . .

9. A material with a negative temperature coefficient means that as temperature:

. . . a. increases, resistance decreases.

. . . b. increases, resistance increases.

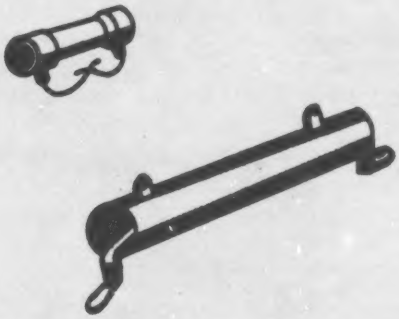
. . . c. changes, the resistance remains constant.

. . . d. decreases, resistance decreases.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

B. Turn to student text volume I and read paragraphs 3-83 through 3-92. Return to this page and answer the following questions.

1. The pictorial diagram represents a:



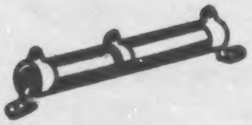
. . . a. carbon resistor.

. . . b. fixed wire resistor.

. . . c. battery.

. . . d. transistor.

2. The pictorial diagram represents a



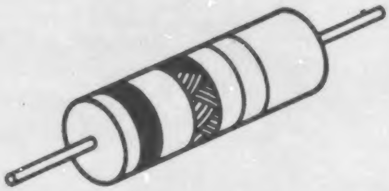
. . . a. carbon resistor.

. . . b. potentiometer.

. . . c. slide tap resistor.

. . . d. tapped wire resistor.

3. The pictorial diagram represents a



. . . a. variable resistor.

. . . b. potentiometer.

. . . c. schematic.

. . . d. fixed carbon resistor.

## ADJUNCT GUIDE

**ANSWERS TO A.**

1. c.
2. ohm
3. R
4. b
5. d
6. length
7. $(\text{radius})^2$ or cross-sectional area
8. resistance
9. a

If you missed ANY questions, review the material before you continue.

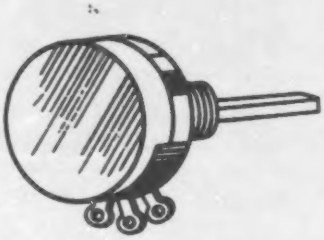
4. The pictorial diagram represents a:

. . . a. fixed wire resistor.

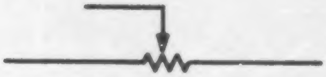
. . . b. slide tap variable resistor.

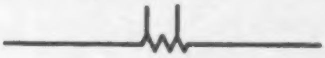
. . . c. Electromechanical device.

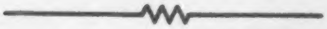
. . . d. potentiometer or variable resistor.



5. Identify the schematic symbol for these resistors:

a.  . . . . . . . . . . . . . . . . . . . . . . .

b.  . . . . . . . . . . . . . . . . . . . . . . .

c.  . . . . . . . . . . . . . . . . . . . . . . .

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

C. Turn to student text volume I and read paragraphs 3-93 through 3-116. Return to this page and answer the following questions.

1. List three requirements for a circuit.

a. . . . . . . . . . . . . . . . . . .

b. . . . . . . . . . . . . . . . . . .

c. . . . . . . . . . . . . . . . . . .

2. The purpose of a power dissipating device is to . . . . . . . . . . . . . . . . . . . . . .

3. Battery cells are connected in series to . . . . . . . . . . . . . . . . . . . . . . . . .

4. Battery cells are connected in parallel to . . . . . . . . . . . . . . . . . . . . . . . .

5. Complete figure 7.

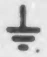
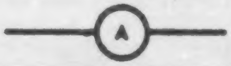
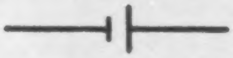
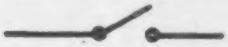
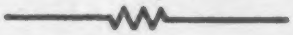
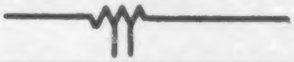
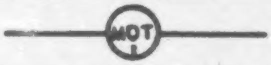
| | SYMBOL | TITLE |
|---|---|---|
| A. |  | |
| B. | | RHEOSTAT |
| C. |  | |
| D. |  | |
| E. | | CROSSED OVER WIRES NOT CONNECTED |
| F. | | LAMP |
| G. |  | |
| H. | | FUSE |
| I. | | BATTERY |
| J. |  | |
| K. | | VOLTMETER |
| L. |  | |
| M. | | CROSSED OVER WIRES CONNECTED |
| N. |  | |
| O. | | FIXED RESISTOR |

Figure 7

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

* * * * * * *

**ADJUNCT GUIDE**

**ANSWERS TO B.**

1. b
2. c
3. d
4. d

5a. Variable resistor or potentiometer
5b. Tapped resistor
5c. Fixed resistor

If you missed ANY questions, review the material before you continue.

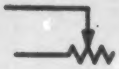
**ANSWERS TO C.**

1. Source of EMF
   Conductor
   Power dissipating device

2. Perform work
3. Increase voltage
4. Increase current

5a. Ground

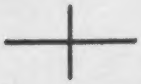
b.



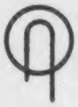
c. Ammeter

d. Battery

e.

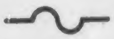


f.

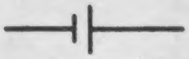


g. Switch

h.

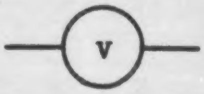


i.



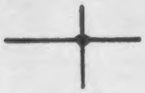
j. Resistor

k.



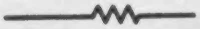
l. Tapped resistor

m.



n. Motor

o.



D. Turn to student text volume I and read paragraphs 3-117 through 3-135. Return to this page and answer the following questions.

1. Record the value of the following color coded resistors:

a. Brown-Red-Red-Gold ..........................
b. Red-Yellow-Red ..........................
c. Yellow-Violet-Yellow ..........................
d. Brown-Black-Brown-Gold ..........................
e. Gray-Red-Green-Gold-Yellow ..........................
f. Orange-White-Gold-Gold ..........................
g. Brown-Black-Silver-Gold ..........................

2. A 500- to 600-ohm resistor is required to repair a radar set. The parts man offers a choice of four. Select the correct one by color code.

. . . a. Green-Blue-Brown-Silver

. . . b. Green-Blue Black-Gold

. . . c. Green-Blue-Violet

. . . d. Blue-Green-Brown-Gold-Yellow

3. What is the ohmic value of a resistor with a color code of Green-Red-Yellow-Silver?

. . . a. 52,000 ± 10% ohms.

. . . b. 520,000 ± 10% ohms.

. . . c. 524 ± 10% ohms.

. . . d. 4,200,000 ± 10% ohms.

4. Determine the color coding for the following resistor values:

a. 2500 ohms. . . . . . . . . . . . . . . . . . . . . . .

b. 130,000 ± 10% ohms. . . . . . . . . . . . . . . . . . . . . . .

c. 10 ± 5% ohms. . . . . . . . . . . . . . . . . . . . . . .

d. 74,000 ohms. . . . . . . . . . . . . . . . . . . . . . .

5. When all three bands are red, the resistor value is:

. . . a. 2.20 ohms.

. . . b. 222 kilohms.

. . . c. 222 ohms.

. . . d. 2200 ohms.

6. When using resistor color code, gold or silver in the third band:

. . . a. is not used.

. . . b. represents a precision resistor.

. . . c. represents a special tolerance.

. . . d. identifies a decimal multiplier.

7. When a fourth band is not used, it means the:

. . . a. Third band is used as a divisor.

. . . b. Body-end-dot system is being used.

. . . c. Third band becomes the tolerance band.

. . . d. Tolerance of the resistor is 20%.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ADJUNCT GUIDE

**ANSWERS TO D.**

1a. 1200 ± 5% ohms.
 b. 2400 ± 20% ohms
 c. 470,000 ± 20% ohms
 d. 100 ± 5% ohms.
 e. 8.2 megohms ± 5%
   Failure rate 0.001%
 f. 3.9 ± 5% ohms
 g. 0.1 ± 5% ohms

2. a
3. b
4a. Red-Green-Red
 b. Brown-Orange-Yellow-Silver
 c. Brown-Black-Black-Gold
 d. Violet-Yellow-Orange
5. d
6. d
7. d

If you missed ANY questions, review the material before you continue.

E. Turn to Laboratory Exercise 5-1. This exercise will prepare you for your progress check.

AFTER COMPLETING THE LABORATORY EXERCISE AND PROGRESS CHECK, YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## RESISTANCE, RESISTORS, AND SCHEMATIC SYMBOLS

### Resistor Color Code

**OBJECTIVES:**

1. Determine the assigned value of composition resistors using a color code chart.

2. Calculate minimum and maximum tolerance limits of resistor ohmic values.

**EQUIPMENT:** Trainer 5218, DC Resistor

**REFERENCES:** Student Text, volume I, paragraphs 3-117 through 3-135

> CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

**PROCEDURE:** So, you are now ready for a laboratory exercise. Do you remember the statements on safety? Return to KEP-GP-1 and read the section on safety again before proceeding on this exercise.

1. Place the DC trainer (figure 8) on the bench in front of you.

2. Locate resistors R1 through R11 on the trainer.

3. Use the resistors on the trainer and the Color Code Chart, figure 9, to complete figure 10.

LABORATORY EXERCISE 5-1

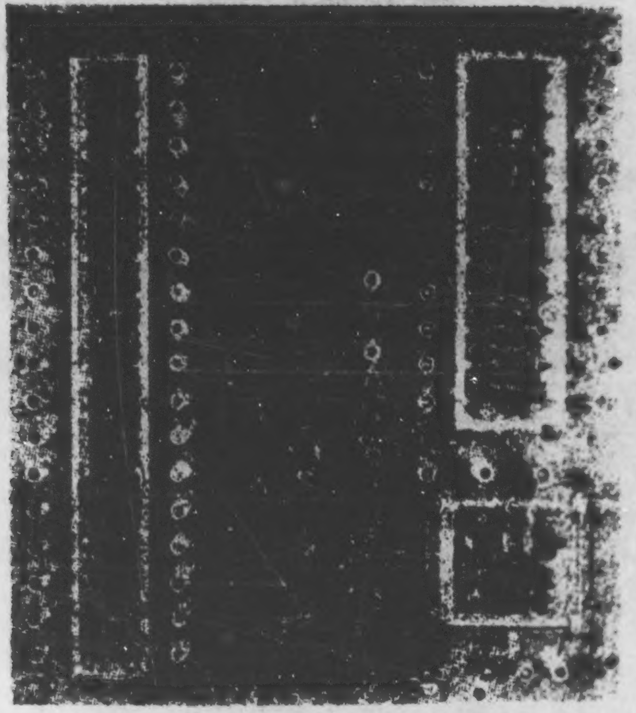


Figure 8

| COLOR | PART | SIGNIFICANT FIGURES OF ELECTRICAL VALUE | | | TOLERANCE | FAILURE RATE PER 1000 HRS |
|---|---|---|---|---|---|---|
| | | 1st Number | 2nd Number | Multiplier | | |
| Black | Capacitor | 0 | 0 | 1 | ±20% | L 5% |
| Brown | --- | 1 | 1 | 10 | ± 1% | M 1% |
| Red | --- | 2 | 2 | 100 | ± 2% | P 0.1% |
| Orange | --- | 3 | 3 | 1000 | --- | R 0.01% |
| Yellow | --- | 4 | 4 | 10000 | --- | S 0.001% |
| Green | Diode | 5 | 5 | 100000 | --- | T 0.0001% |
| Blue | --- | 6 | 6 | 1000000 | --- | |
| Violet | --- | 7 | 7 | 10000000 | --- | |
| Gray | --- | 8 | 8 | | --- | |
| White | --- | 9 | 9 | | --- | |
| Gold | --- | - | - | 0.1 | ± 5% | |
| Silver | Coil | - | - | 0.01 | ±10% | |

Figure 9

BEST COPY

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| RESISTOR NUMBER | 1 COLOR CODE VALUE (Numerical) | 2 TOLERANCE MINIMUM AND MAXIMUM RESISTANCE |
|---|---|---|
| R1 | | |
| R2 | | |
| R3 | | |
| R4 | | |
| R5 | | |
| R6 | | |
| R7 | | |
| R8 | | |
| R9 | | |
| R10 | | |
| R11 | | |

Figure 10

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

LABORATORY EXERCISE 5-1

ANSWERS TO LABORATORY EXERCISE 5-1.

| RESISTOR NUMBER | 1 COLOR CODE VALUE (Numerical) | 2 TOLERANCE MINIMUM AND MAXIMUM RESISTANCE |
|---|---|---|
| R1 | 1,000Ω | 950Ω– 1,050Ω |
| R2 | 4,700Ω | 4,465Ω– 4,935Ω |
| R3 | 5,100Ω | 4,845Ω– 5,355Ω |
| R4 | 10 kΩ | 9.5 kΩ-10.5 kΩ |
| R5 | 22 kΩ | 20.9 kΩ-23.1 kΩ |
| R6 | 27 kΩ | 25.65 kΩ-28.35 kΩ |
| R7 | 47 kΩ | 44.65 kΩ-49.35 kΩ |
| R8 | 100 kΩ | 95 kΩ-105 kΩ |
| R9 | 220 kΩ | 209 kΩ-231 kΩ |
| R10 | 5,100Ω | 4,845Ω– 5,355Ω |
| R11 | 10 kΩ | 9.5 kΩ-10.5 kΩ |

If you missed ANY questions, review the reference material before you continue.

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

## RESISTANCE, RESISTOR, AND SCHEMATIC SYMBOLS

1. The opposition to current flow is described as . . . . . . . . . . . . . . . . . . . . . .

2. The unit of measurement for resistance is the . . . . . . . . . and the quantity symbol is . . . . . . . . .

3. Draw the schematic symbols for the following resistors.

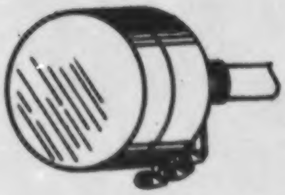
   a. Fixed.

   b. Tapped.

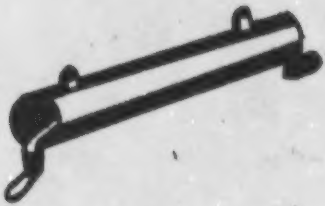
   c. Variable

4. Label each of the resistor pictorials.

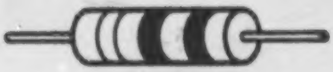
   a. . . . . . . . . . . . . . . . . . . . .



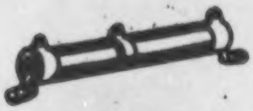
   b. . . . . . . . . . . . . . . . . . . . .



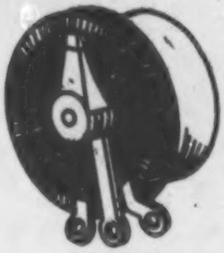
   c. . . . . . . . . . . . . . . . . . . . .



   d. . . . . . . . . . . . . . . . . . . . .



   e. . . . . . . . . . . . . . . . . . . . .



## MODULE SELF-CHECK

5. Draw the schematic symbol for a

   a. battery.

   b. fuse.

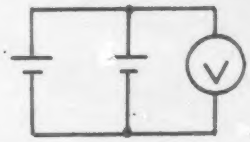
   c. conductor.

   d. lamp.

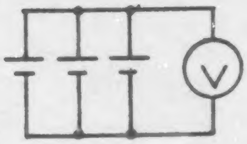
   e. switch.

6. Which battery connection has the greatest output voltage?

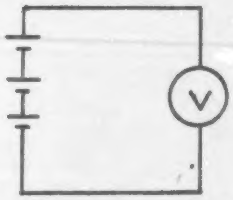
. . . a.



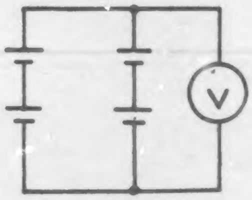
. . . b.



. . . c.



. . . d.



CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

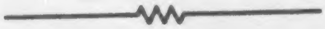
## NOTES

## MODULE SELF-CHECK

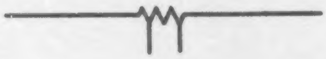
### ANSWERS TO MODULE SELF-CHECK

1. resistance
2. ohm Ω

3a.



b.



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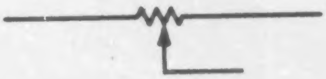
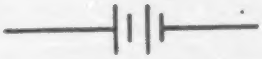
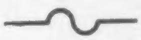


4a. potentiometer
b. fixed wire
c. carbon
d. slide tap
e. potentiometer

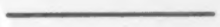
5a.



b.



c.



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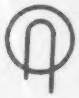
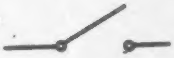


e.



6. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR GUIDANCE.

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Prepared by Keesler TTC
KEP-GP-6

Technical Training

# Electronic Principles (Modular Self-Paced)

## Module 6

## MULTIMETER USES

1 September 1975

AIR TRAINING COMMAND

Designed For ATC Course Use

ATC Keesler 5-3309

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1 September 1975

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 6

## MULTIMETER USES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

| Title | Page |
|---|---|
| Overview | 1 |
| List of Resources | 1 |
| Adjunct Guide | 1 |
| Laboratory Exercise 6-1 | 3 |
| Laboratory Exercise 6-2 | 4 |
| Laboratory Exercise 6-3 (Deleted) | 6 |
| Laboratory Exercise 6-4 | 7 |
| Module Self-Check | 8 |
| Answers | 10 |

## OVERVIEW

1. SCOPE: When working with electronic circuits, it is necessary to measure current, voltage, and resistance. A single instrument that can make these measurements is the multimeter. In this module you will become familiar with the operation and use of the AN/PSM-6 Multimeter.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives.

a. From a group of statements concerning the multimeter, select the one which identifies the purpose of a

(1) function switch.

(2) range switch.

(3) ohms zero adjust.

b. Given a multimeter, identify the

(1) test leads.

(2) voltage scales.

(3) current scales.

(4) resistance scales.

(5) polarities.

c. Using the multimeter and trainer, measure resistance, AC voltage, and DC voltage within ±10 percent accuracy.

AT THIS POINT YOU MAY TAKE THE MODULE SELF-CHECK OR GO TO LABORATORY EXERCISE 6-1.

---

Supersedes Guidance Package KEP-GP-6, 1 July 1974. Previous edition may be used.

## LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

**READING MATERIALS:**

Digest

Adjunct Guide with Student Text

**AUDIOVISUALS:**

Television Lesson, Voltmeter, TVK30-101I

Television Lesson, Ammeter, TVK30-101J

Television Lesson, Ohmmeter, TVK30-101K

**LABORATORY EXERCISES:**

6-1, Resistance Measurement

6-2, DC Voltage Measurement

6-3, Direct Current Measurement (deleted)

6-4, AC Voltage Measurement

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

---

## ADJUNCT GUIDE

**INSTRUCTIONS:**

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to Student Text Volume I and read paragraphs 4-1 through 4-22. Return to this page and answer the following questions.

1. When the FUNCTION switch is in the OHMS position, the PSM-6 can be used to measure ______________.

2. How many RANGE positions are there for ohmmeter operation?

____a. 7 ____c. 6

____b. 4 ____d. 5

3. Never connect the ohmmeter to a/an ______________ circuit.

4. The ohmmeter section of the PSM-6 is zeroed with the ____________________.

5. A SHORT is defined as ______________ resistance.

6. An OPEN is defined as ______________ resistance.

7. The OHMS SCALE on the meter is read from ______________ to ______________.

8. The color of the OHMS SCALE is ________________.

9. Maximum deflection of the pointer indicates ______________ resistance.

10. If a resistor measured 50 on the OHMS SCALE with the RANGE switch in the Ω x 100 position, what would its reading be on the Ω x 1000 scale?

____a. 5 ____c. 500

____b. 50 ____d. 5000

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

---

B. Turn to Laboratory Exercise 6-1. The exercise will increase your proficiency in the use of the PSM-6 to measure resistance. Return and continue with this program upon completion of the laboratory exercise.

---

C. Turn to Student Text Volume I and read paragraphs 4-23 through 4-38. Return to this page and answer the following questions.

1. When the FUNCTION switch of the PSM-6 is in the DC 20KΩ/V position the multimeter is set to measure ____________.

2. The polarity of the red lead is ____________.

3. The polarity of the black lead is ____________.

4. When measuring DC voltage there are ________ ranges available.

5. The color of the DC voltage scale is ____________.

6. When measuring an unknown DC voltage, always begin on the ________ range.

7. Meter damage may result if ________ voltage is applied.

8. If the meter pointer moves to the left, the ____________ must be reversed.

9. Voltage measurements are always taken in (series) (parallel) with the component.

10. If you were going to measure a DC voltage of 125 volts, what range setting should you use?

____a. 250 ____c. 1000

____b. 500 ____d. 150

11. When measuring a negative voltage using ground as a reference, which lead should be connected to ground?

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

---

D. Turn to Laboratory Exercise 6-2. This exercise will increase your proficiency in the use of the PSM-6 to measure DC voltages. Return and continue with this program upon completion of the laboratory exercise.

---

E. Turn to Student Text Volume I and read paragraphs 4-39 through 4-57. Return to this page and answer the following questions.

1. To measure current the FUNCTION switch must be placed in the ________ or ________ positions.

2. Current is read on the ________ scale.

3. To measure current of unknown value, start with the ________ range.

4. The ammeter is placed in (series) (parallel) with the circuit component.

5. The black lead is connected to the ________ point in the circuit.

6. The red lead is connected to the ____________ point in the circuit.

7. What scale would be the most accurate to measure 125 milliamperes?

____a. 1000 ____c. 250

____b. 500 ____d. 50

8. If 1,000,000 microamperes equals 1 ampere, how many milliamperes equals 1 ampere?

____a. 10 ____c. 1000

____b. 100 ____d. 10,000

9. Assuming the RANGE switch is in the 1000 position, what would a reading of 4 on the bottom scale be equal to in milliamperes?

____a. 400 ____c. 4

____b. 25 ____d. 4000

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

---

F. Deleted.

---

G. Turn to Student Text Volume I and read paragraphs 4-58 through 4-59. Return to this page and answer the following questions.

1. To measure AC voltage the FUNCTION switch must be placed in the ____________ position.

2. When measuring AC voltage, the polarity of the test leads (is) (is not) important.

3. The color of the AC volts scale is ____________.

4. To measure an unknown AC voltage always begin on the ____________ range.

5. Voltage measurements are taken in (series) (parallel) with the component.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

---

H. Turn to Laboratory Exercise 6-4. This exercise will increase your proficiency in the use of the PSM-6 to measure AC voltage.

AFTER COMPLETING THE LABORATORY EXERCISE AND PROGRESS CHECK, YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

---

## LABORATORY EXERCISE 6-1
## RESISTANCE MEASUREMENT

OBJECTIVE:

Use the multimeter (PSM-6) to measure resistance within ±10 percent accuracy.

EQUIPMENT:

1. PSM-6
2. DC Resistor Trainer, 5531

REFERENCES:

1. Student Text Volume I, paragraphs 4-1 through 4-22

2. Student Handout, KEP 108, pages 1 through 11

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

## PROCEDURES:

1. Place the DC circuits trainer and PSM-6 before you in a convenient position.

2. Use the PSM-6 as outlined in the above references to measure each resistor.

3. R20 ________ ohms.

4. R22 ________ ohms.

5. R26 ________ ohms.

6. R27 ________ ohms.

7. R29 ________ ohms.

8. R2 ________ ohms.

9. R3 ________ ohms.

10. R5 ________ ohms.

11. R6 ________ ohms.

12. R9 ________ ohms.

CONFIRM YOUR ANSWERS WITH THE INSTRUCTOR.

---

RETURN TO THE RESOURCE FROM WHICH YOU CAME AND CONTINUE WITH THAT PROGRAM.

YOU MAY STUDY ANOTHER RESOURCE, GO TO LABORATORY EXERCISE 6-2, OR TAKE THE MODULE SELF-CHECK.

---

## LABORATORY EXERCISE 6-2
## DC VOLTAGE MEASUREMENT

## OBJECTIVE:

Use the multimeter (PSM-6) to measure DC voltage within ±10 percent accuracy.

## EQUIPMENT:

1. DC Resistor Trainer, 5531
2. DC Power Supply, 4649
3. AN/PSM-6

## REFERENCES:

1. Student Text Volume I, paragraphs 4-23 through 4-38

2. Student Handout, KEP-108, pages 1 through 11

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES, REMOVE WATCHES AND RINGS.

## PROCEDURES:

You are now ready for a laboratory exercise. Do you remember the statements on safety? Return to KEP-GP-1 and read the section on safety before proceeding on this exercise.

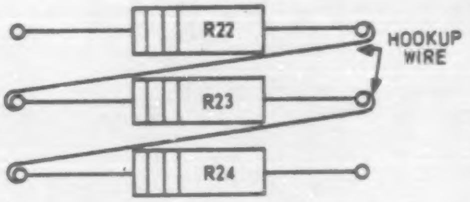
1. Locate the required equipment.

2. Preset the power supply to OFF and turn the VOLTS ADJ fully COUNTERCLOCKWISE.

3. On the trainer locate R22, R23, and R24.

4. Use hookup wire and connect the resistors as shown in figure 2-1.

5. Set the PSM-6 to measure resistance.



REP4-1143

Figure 2-1

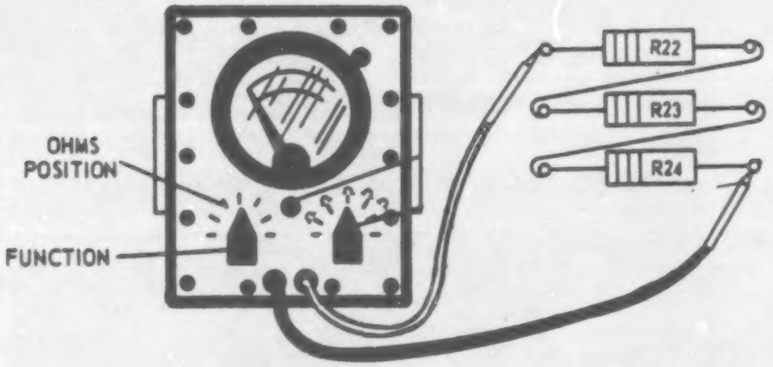


Figure 2-2

6. Connect the PSM-6 as shown in figure 2-2. The total resistance of the three resistors is ____________ ohms.

CONFIRM YOUR ANSWERS IN BACK OF THIS TEXT.

7. Connect the power supply to the resistive network as shown in figure 2-3.

NOTE: Be sure the control marked VOLT ADJ is fully COUNTERCLOCKWISE to prevent an overvoltage condition when power is applied.

STOP. HAVE THE INSTRUCTOR CHECK TRAINER AND POWER SUPPLY WIRING HOOKUP BEFORE THE POWER SUPPLY IS PLUGGED INTO AN AC OUTLET.

8. Plug the power supply cord into an AC outlet.

9. Turn the power supply ON and set the voltage adjust for a reading of 40 on the power supply meter.

10. Set the PSM-6 to measure DC voltage by placing the FUNCTION switch to DC V, 20K/V. Set the RANGE switch to 1000.

11. Measure and record the DC voltage across each resistor. Reduce the RANGE setting of the PSM-6 until the meter is READABLE. This value should be greater than the next lower RANGE setting. If not, again reduce the RANGE setting.

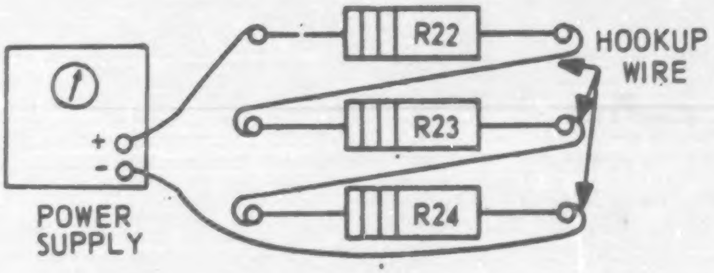


Figure 2-3

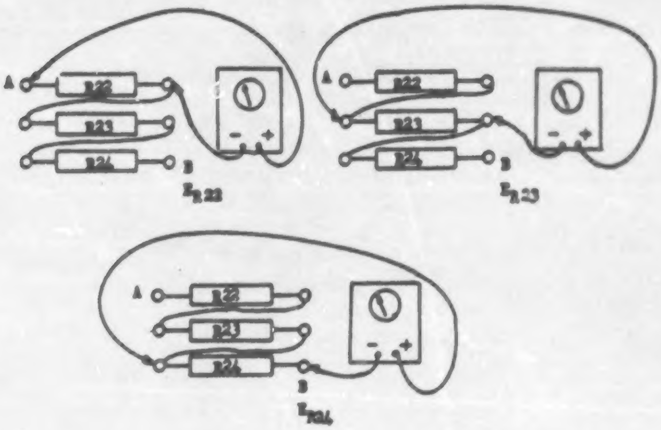


Figure 2-4

See figure 2-4 for meter connections.

R22 = ________________ VDC

R23 = ________________ VDC

R24 = ________________ VDC

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

---

12. Turn off the power supply and disconnect all hookup wires.

RETURN TO THE RESOURCE FROM WHICH YOU CAME AND CONTINUE WITH THAT PROGRAM.

YOU MAY STUDY ANOTHER RESOURCE, GO TO LABORATORY EXERCISE 6-4, OR TAKE THE MODULE SELF-CHECK.

---

## LABORATORY EXERCISE 6-3
## DC MEASUREMENT
## (DELETED)

## LABORATORY EXERCISE 6-4
## AC VOLTAGE MEASUREMENT

**OBJECTIVE:**

Use the multimeter (PSM-6) to measure AC voltage within ±10 percent accuracy.

**EQUIPMENT:**

1. AC Inductor and Capacitor Trainer, 5967
2. AN/PSM-6

**REFERENCES:**

1. Student Text, Volume I, paragraphs 4-58 and 4-59. Review paragraphs 4-23 through 4-38, if necessary.

2. Student Handout, KEP-108, pages 1 through 11

**CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.**

**PROCEDURES:**

1. Locate the required equipment.

2. On the trainer locate the power transformer, T101.

3. Connect a hookup wire from terminal B to terminal D. See figure 4-1.

4. Connect the trainer power cord to an AC outlet.

5. Set the FUNCTION switch of the PSM-6 to ACV, 1 Kohm/V.

6. Measure the AC voltage between the terminals indicated.

Terminals A and B _______VAC

Terminals C and D _______VAC

Terminals A and E _______VAC

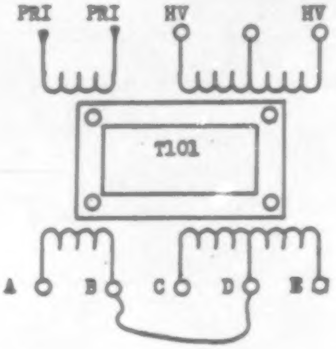


Figure 4-1

**CAUTION: ALWAYS PLACE THE RANGE SWITCH OF THE PSM-6 TO THE HIGHEST RANGE BEFORE CONNECTING THE VOLTMETER. THIS WILL PREVENT DAMAGE TO THE METER. AFTER THE METER IS CONNECTED, REDUCE THE RANGE SWITCH SETTING TO OBTAIN A READABLE VALUE.**

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## MODULE SELF-CHECK

### A. QUESTIONS:

1. When the FUNCTION switch is in the OHMS position the PSM-6 can be used to measure ________________.

2. How many RANGE positions are there for ohmmeter operation?

____a. 7 ____c. 6

____b. 4 ____d. 5

3. Never connect the ohmmeter to a/an ________________ circuit.

4. The ohmmeter section of the PSM-6 is calibrated with the ________________.

5. A SHORT is defined as ____________ resistance.

6. An OPEN is defined as ____________ resistance.

7. The OHMS SCALE on the meter reads from ________ to __________.

8. The color of the OHMS scale is ________________.

9. Maximum deflection of the pointer indicates ____________ resistance.

10. If a resistor measured 50 on the OHMS scale with the RANGE switch on the Ω x 100 position, what would be the scale reading on the Ω x 1000 position of the RANGE switch?

____a. 5 ____c. 500

____b. 50 ____d. 5000

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

### B. QUESTIONS:

1. When the FUNCTION switch of the PSM-6 is in the DC 20 Kohms/V position, the multimeter is set to measure __________.

2. The polarity of the red lead is ________________.

3. The polarity of the black lead is ________________.

4. When measuring DC voltage there are ________________ ranges available.

5. The color of the DC voltage scale is ________________.

6. When measuring an unknown DC voltage, always begin on the ____________ range.

7. Meter damage may result if __________ voltage is applied.

8. If the meter pointer moves to the left,

the __________ must be reversed.

9. Voltage measurements are always taken in (series) (parallel) with the component.

10. If you were going to measure a DC voltage of 125 volts, what range setting should you use?

____a. 250 ____c. 1000

____b. 500 ____d. 150

11. When measuring a negative voltage using ground as a reference, which lead should be connected to ground?

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

---

## C. QUESTIONS:

1. To measure current the FUNCTION

switch must be placed in the __________

or __________ positions.

2. Current is read on the ________ scale.

3. To measure current of unknown value,

start with the __________ range.

4. The ammeter is placed in (series) (parallel) with the circuit component.

5. The black lead is connected to the

__________ point in the circuit.

6. The red lead is connected to the

__________ point in the circuit.

7. What scale would be the most accurate to measure 125 milliamperes?

____a. 1000 ____c. 250

____b. 500 ____d. 50

8. If 1,000,000 microamperes equals 1 ampere, how many milliamperes equals 1 ampere?

____a. 10 ____c. 1000

____b. 100 ____d. 10,000

9. Assuming the RANGE switch is in the 1000 position, what would a reading of 4 in the bottom scale be equal to in milliamperes?

____a. 400 ____c. 4

____b. 25 ____d. 4000

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

---

## D. QUESTIONS:

1. To measure AC voltage the FUNCTION

switch must be placed in the __________ position.

2. When measuring AC voltage, the polarity of the test leads (is) (is not) important.

3. The color of the AC volts scale is

__________.

4. To measure an unknown AC voltage

always begin on the __________ range.

5. Voltage measurements are taken in (series) (parallel) with the component.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS TEXT.

ANSWERS TO ADJUNCT GUIDE A:

1. resistance
2. d
3. hot/operational
4. ohms zero adjust
5. zero
6. infinite
7. right to left
8. green
9. zero
10. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO ADJUNCT GUIDE C:

1. DC voltage
2. positive
3. negative
4. seven
5. black
6. 1000
7. excessive
8. leads
9. parallel
10. a
11. the positive

If you missed ANY questions review the material before you continue.

ANSWERS TO ADJUNCT GUIDE E:

1. DC MA or 100 microampere SPECIAL
2. black
3. 1000
4. series
5. negative
6. positive
7. c
8. c
9. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO ADJUNCT GUIDE G:

1. AC V
2. is not
3. blue
4. 1000
5. parallel

If you missed ANY questions, review the material before you continue.

ANSWERS TO LAB EXERCISE 6-2:

6. 400 ohms ±10 percent

If you missed the question, ask the instructor for assistance.

11. R22 = 9 to 11 VDC
    R23 = 9 to 11 VDC
    R24 = 18 to 22 VDC

If you missed the question, ask your instructor for assistance.

## ANSWERS TO LAB EXERCISE 6-3: (DELETED)

## ANSWERS TO LAB EXERCISE 6-4:

The results of the voltage measurements should be within ±10 percent of the following:

| | |
|---|---|
| Terminals A and B | 5.4 VAC |
| Terminals C and D | 3.2 VAC |
| Terminals A and E | 8.6 VAC |

If you missed any questions, ask your instructor for assistance.

Disconnect all equipment.

## ANSWERS TO MODULE SELF-CHECK A:

1. resistance
2. d
3. hot/operational
4. ohms zero adjust
5. zero
6. infinite
7. right to left
8. green
9. zero
10. a

## ANSWERS TO MODULE SELF-CHECK B:

1. DC voltage
2. positive
3. negative
4. seven
5. black
6. 1000
7. excessive
8. leads
9. parallel
10. a
11. the positive

## ANSWERS TO MODULE SELF-CHECK C:

1. DC mA or 100 microampere SPECIAL
2. black
3. 1000
4. series
5. negative
6. positive
7. c
8. c
9. a

**ANSWERS TO MODULE SELF-CHECK D:**

1. AC V

2. is not

3. blue

4. 1000

5. parallel

**HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.**

ATC PT 3AQR3X020-X
Prepared by Keesler TTC
KEP-PT-7

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 7

## SERIES RESISTIVE CIRCUITS

1 January 1975

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 6-2876

DO NOT USE ON THE JOB

Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Programmed Text 3AQR3X020-X
KEP-PT-7
1 Jan 1975

This illustrated Programmed Text is designed to aid in the study of Series Resistive Circuits. Each page contains an important idea or concept to be understood before proceeding to the next. An illustration for each objective is presented to clarify what is to be learned.

At the bottom of each page, there are a few questions to bring out the main points. These are indicated by.... It is hoped that these questions also aid in understanding the subject a little better.

Q-1 or Q-2 etc..

The answers to these questions will be found on the top of a following page, indicated as ..... Short comments may follow the answers to help understand why a question may have been missed.

A-1 or A-2 etc..

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## OBJECTIVES

Upon completion of this module, you should be able to satisfy the following objectives:

a. Given four diagrams, select the one which satisfies the requirements for a DC circuit.

b. From a group of statements, select the one that describes Ohm's Law as related to current, voltage, and resistance.

c. Given a series circuit schematic diagram and formulas, solve for:

(1) total resistance.

(2) total current.

(3) total power.

## INTRODUCTION

What is a radio? It is a group of electronic parts, connected together in a certain way. Connect them together another way, and a Stereo Amplifier can result. These same parts, wired together in a different manner will make a Walkie-Talkie.

All electronic equipment is simply; the right kind of parts, connected together the right way. Disassemble a Radar System, and re-connect the parts into a Television transmitter and receiver. An Airborne Navigation System uses many of the same parts as an Electronic Calculator. FM Stereo radios, and Ground Radio receivers, use the same parts. It's the way the parts are connected that "counts".

There are several fundamental methods of interconnecting the parts. One of them is called...."connecting them in Series". It is the "basic" method, and is used as the starting-point in most Electronic courses. This text involves such "Series Circuits".

There are three principle factors within all electric circuits. these are: Voltage, Current, and Resistance. They will be reviewed, and expanded upon. A new subject, "electrical power" is introduced.

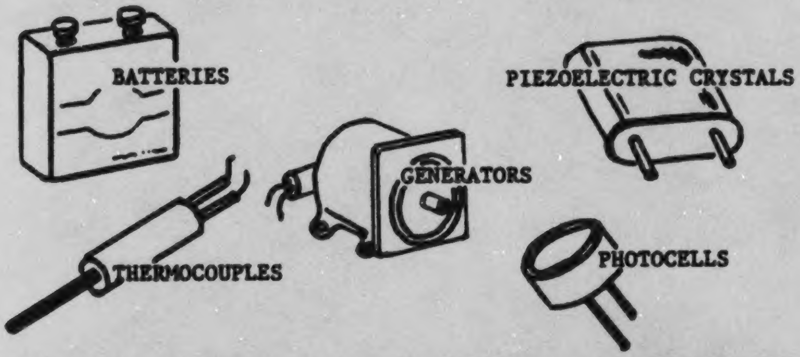
Series Circuits, and the calculations involved in them, are the "foundation". Your understanding of these circuits is important.

## ELECTRIC CIRCUIT REQUIREMENTS

All electrical circuits, to be useful, must have the following basic parts:

1. A "source" of electrical power (battery)
2. Electrical conductors (wires)
3. A current "controlling" device (resistor)

## SOURCES OF ELECTRICAL POWER

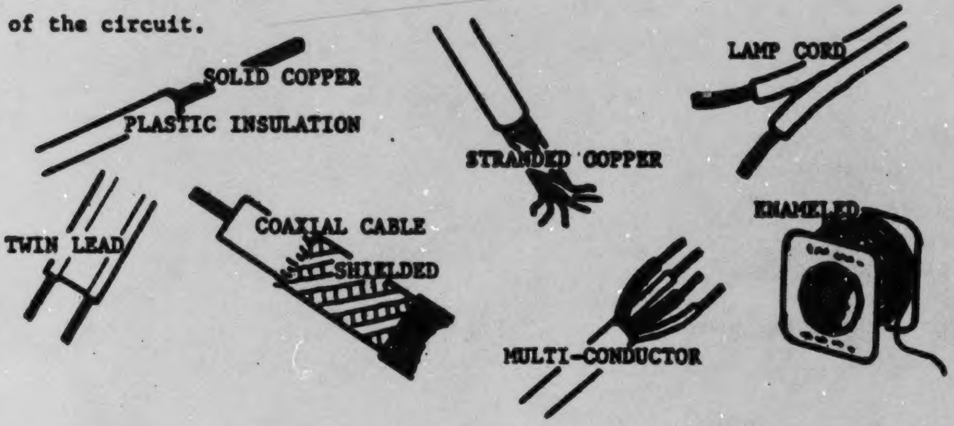


Q-1 a. The three requirements for a practical electrical circuit are: A source of power, conductors, and a ____________ controlling device.

b. T-F "Continuity" is NOT necessary.

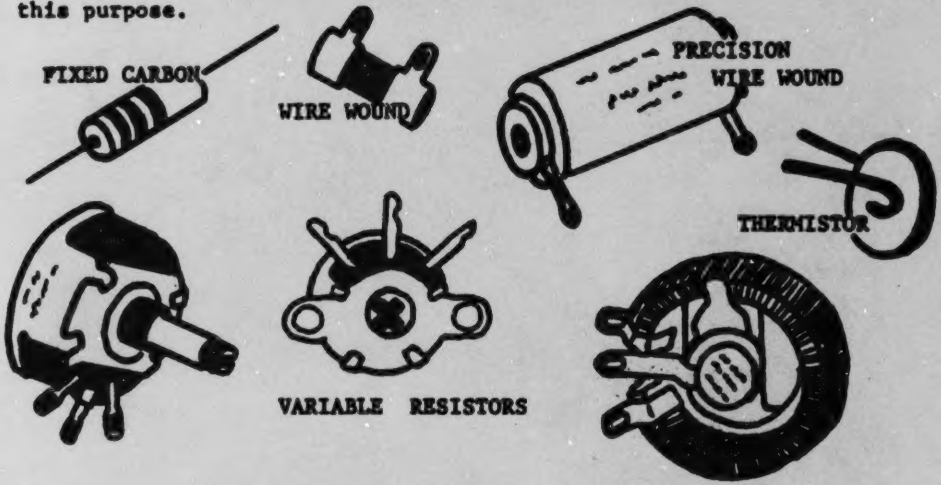
## ELECTRICAL CONDUCTORS

The most common type of electrical conductor is copper wire. Many different types of wire are used, depending on the requirements of the circuit.



## CURRENT CONTROLLING DEVICES

Resistors are the most often used "current controlling" device. Along with resistors, many other electronic components are used for this purpose.



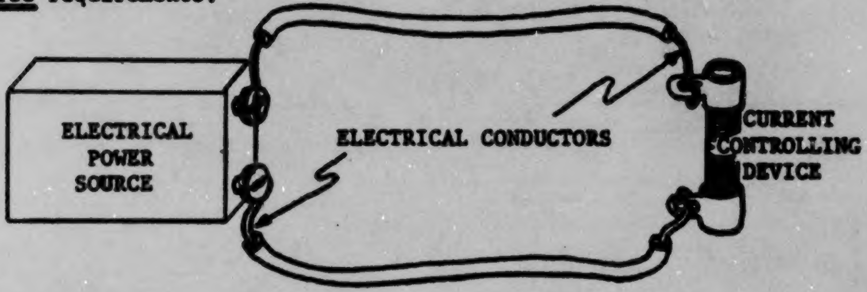
Other "current controlling" devices such as: transistors, tubes, capacitors, inductors, (and many more), will be covered later on in training. For now, only the resistor will be discussed.

Q-2 a. The most common conductor material is _____________ wire.
b. T-F Resistors are the only "current controlling devices".

A-1 a. current controlling device.
b. False..."continuity" means....a complete circuit, hooked-up.

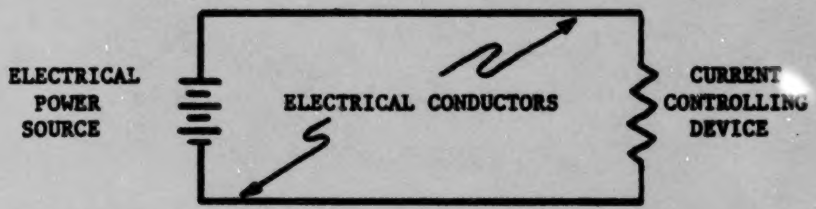
## BASIC CIRCUIT CONSTRUCTION

A simple electrical circuit can now be constructed, to meet the three requirements.



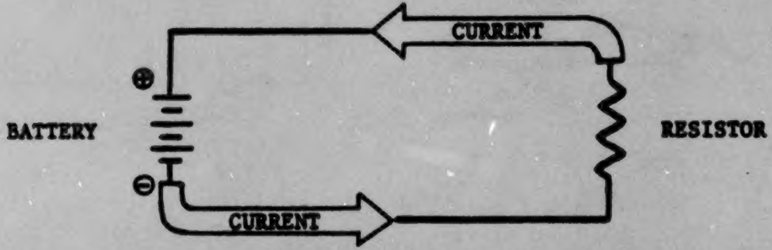
## SCHEMATIC DIAGRAM

The "schematic diagram", using schematic symbols, is shown below.



## ELECTRICAL CURRENT FLOW

The movement of electrons (current) thru the circuit, would be from the "negative" terminal of the battery (the short line), around thru the resistor, and back into the "positive" terminal of the battery (the long line). Thus it is said that, "current flows from negative to positive".



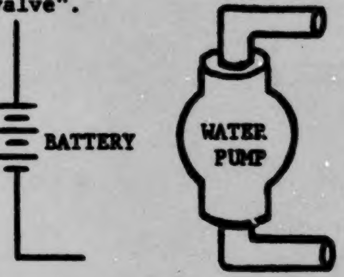
Q-3 a. The three requirements for a practical electrical circuit are: A source of power, conductors, and a current ________ device.

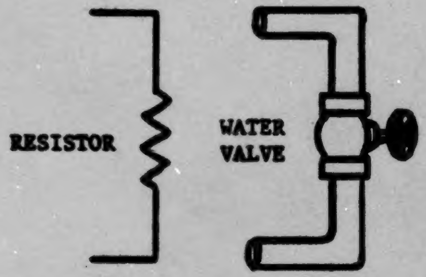
b. Electrical current flows from ____________ to ____________.

A-2 a. copper......sometimes aluminum is used for light weight.
b. False....transistors, tubes etc. also control current.

## HYDRAULIC ANALOGY

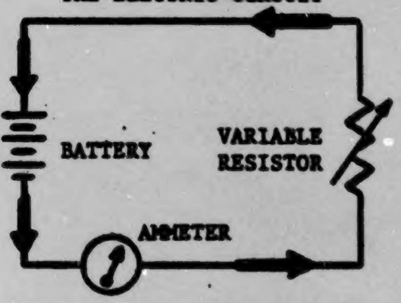
The study of the movement of liquids is called "Hydraulics". It may be of some help at this time, to see the similarity between "control of the flow of electrons", and "control of the flow of water". Consider the battery as a water "pump", and the resistor as a water "valve".



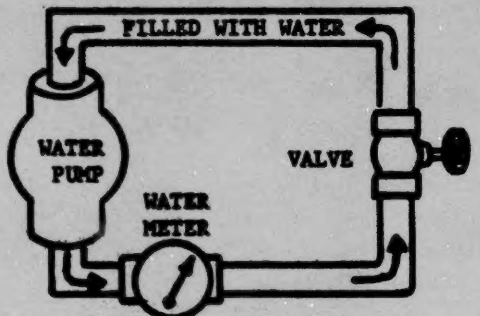


Another important part of the hydraulic system is a water "meter", used to measure the flow of water. In the electric circuit, this part is an "ampere-meter" (ammeter), used to measure the flow of electrons.

THE ELECTRIC CIRCUIT



THE HYDRAULIC CIRCUIT



The battery "pressure" (voltage), forces electrons to flow (current) thru the "opposition" (resistance) of the resistor.

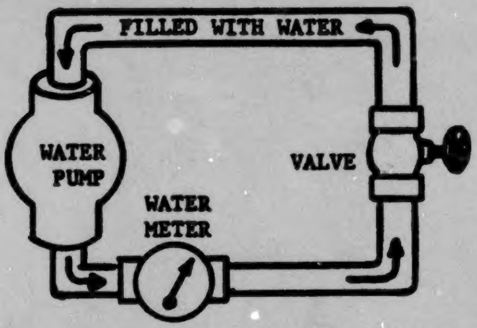
The pump "pressure", forces water to flow thru the opposition of the valve.

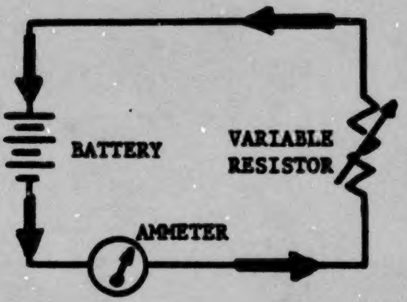
Q-4 a. A valve controls the flow of water, like a ____________ controls the flow of electrons.
b. A resistor ____________ the flow of electrons.

A-3 a. controlling
b. negative to positive.

**HYDRAULIC ANALOGY** (cont)

In the hydraulic circuit, the same water is forced "around-and-around" thru the system. In the electric circuit, the same electrons are forced "around-and-around" thru the circuit.





| FACTORS AFFECTING WATER FLOW | | FACTORS AFFECTING ELECTRON FLOW |
|---|---|---|
| 1. Water pump pressure. | → | 1. Battery pressure (voltage). |
| 2. Opposition (setting) of the valve. | | 2. Opposition (resistance) of the resistor. |

| | | |
|---|---|---|
| Increasing the pump pressure, will force more gallons-per-minute thru the valve, and the water meter will read higher. | → | Increasing the battery pressure (more voltage), will force more coulombs per second (current) thru the resistor, and the ammeter will read higher. |
| Reducing the opposition of the valve (opening the valve more), will allow more gallons-per-minute to flow arround thru the system, and the water meter will read higher. | → | Reducing the opposition of the resistor (less ohms), will allow more coulombs-per-second to flow around thru the circuit, and the ammeter will read higher. (One ampere = 1 coulomb-per-sec) |
| Reducing the pump pressure, reduces the flow of water thru the system. | → | Reducing the battery voltage, reduces the flow of electrons (current) thru the circuit. |
| Increasing the opposition of the valve (tightening it down), reduces the flow of water thru the system. | → | Increasing the opposition of the resistor (more ohms), reduces the flow of electrons thru the circuit. |

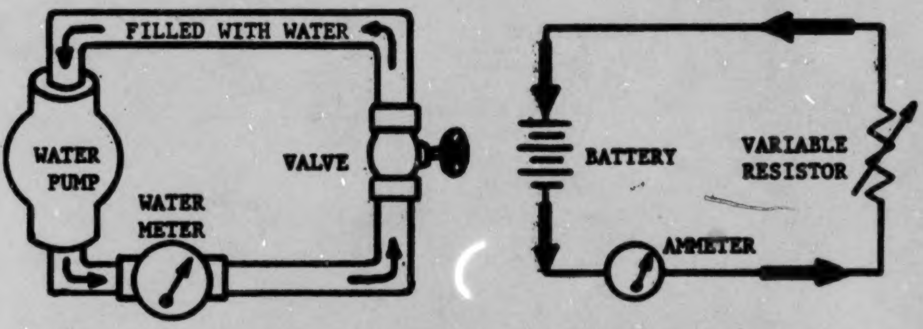
Q-5 a. If the opposition of the resistor is reduced, the flow of current thru the circuit will ________________(inc or dec).

A-4
a. resistor b. controls, limits, regulates, etc..

**HYDRAULIC ANALOGY** (cont)

In the hydraulic circuit, the amount of water "allowed" to flow, depends upon the setting of the valve. The valve regulates or controls the amount of water flowing to the desired level.

In the electric circuit, a resistor of the proper opposition (ohms) is chosen, to limit, regulate, or control the flow of electrons to the desired number of amperes.



| | | |
|---|---|---|
| Changing the pump pressure, has NO effect on the setting of the valve. | ➡ | Changing to a different battery has NO effect on the opposition (ohms) of the resistor. |
| Changing the opposition of the valve, has NO effect on the pump pressure. | ➡ | Changing the opposition (ohms) of the resistor, has NO effect on the battery voltage. |
| Changing the pump pressure, or the opposition of the valve, WILL change the amount of water flowing thru the system. | ➡ | Changing the battery voltage, or the opposition (ohms) of the resistor, WILL change the amount of electrons flowing thru the circuit. |

Q-6 Answer the following with: increase, decrease, or remain the same.

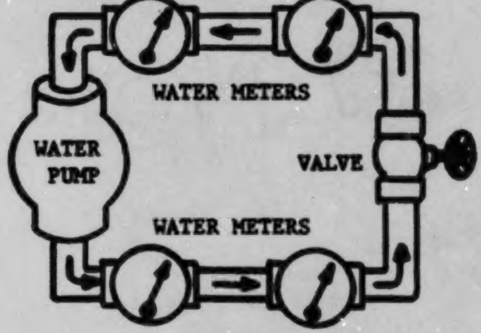
a. If resistance increases, the current will ____________.
b. If voltage increases, the current will ____________.
c. If current increased, the resistance must have ____________.
d. If current decreased, the voltage must have ____________.
e. If resistance increases, the voltage will ____________.
f. If voltage decreases, the resistance will ____________.
g. If resistance decreases, current will ____________.
h. If voltage increases, the resistance will ____________.

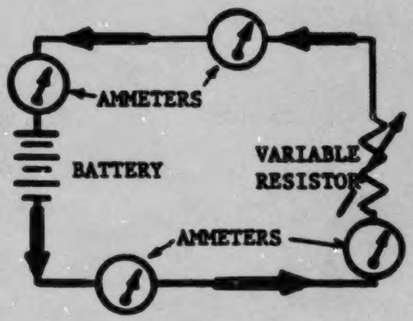
A-5

a. **increase.... reducing the opposition of the valve allows more water to flow thru the system. Reducing the opposition to the flow of electrons, allows more current to flow.**

## MEASURING CURRENT

It is important at this point, to understand that the amount of current flowing can be measured at any point in the circuit, and the readings will be the same.





All of the water meters in the hydraulic system will have the same reading, because they are all measuring the same water flowing thru them.

➡

All of the ammeters in the electric circuit will have the same reading, because they are all measuring the same electrons flowing thru them.

## HYDRAULIC ANALOGY SUMMARY

The principle function of a valve in a hydraulic system, is to control the flow of water thru the system. The flow of water can be measured at any point in the system. The force required to cause water to move, is provided by the pump. Although changes in pump pressure will affect the flow, it is the valve that determines how much water will actually be "allowed" to flow.

## ELECTRIC CIRCUIT SUMMARY

The principle function of a resistor in an electric circuit, is to control the flow of electrons thru the system. The flow of electrons can be measured at any point in the circuit. The force required to cause the electrons to move, is provided by the battery. Although changes in battery voltage affect the flow, it is the resistor that determines how many electrons will actually be "allowed" to flow.

**A-6**

a. decrease....there is more opposition.
b. increase....there is more force (voltage).
c. decreased...assuming the voltage remained the same.
d. decreased...assuming the resistance remained the same.
e. remain the same...but there will be less current flowing.
f. remain the same...but there will be less current flowing.
g. increase....because there is less opposition.
h. remain the same....but there will be more current flowing.

## OHMS LAW

The function of a resistor, is to control the amount of current flowing thru an electric circuit. The actual amount of current, in amperes, can be calculated using "OHMS LAW".

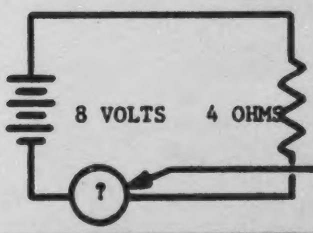
**Ohms Law** The current in any electric circuit is directly proportional to voltage, and inversely proportional to resistance.

**Which Means** If voltage increases, the current will increase. If resistance increases, the current will decrease.

**In Equation Form**

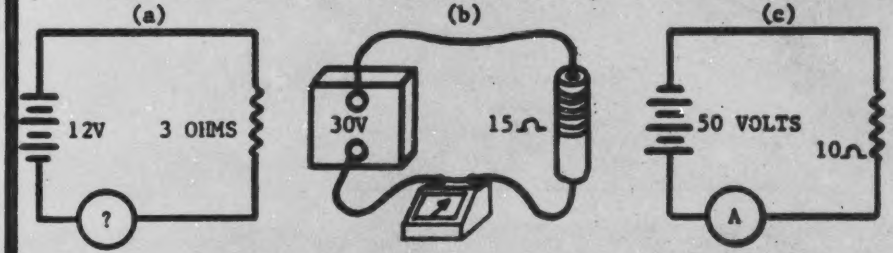
$$\text{CURRENT} = \frac{\text{VOLTAGE}}{\text{RESISTANCE}} \qquad \boxed{I = \frac{E}{R}}$$

EXAMPLE: Calculate the amount of current allowed to flow in the following electric circuit.



$$I = \frac{E}{R} = \frac{8 \text{ VOLTS}}{4 \text{ OHMS}} = 2 \text{ AMPERES}$$

Q-7 Solve for the amount of current flowing in the circuits below.



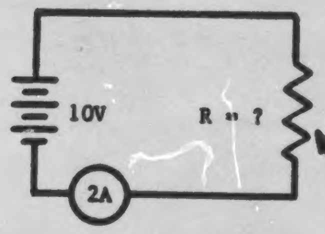
## RESISTANCE CALCULATION

The opposition (ohms) of a resistor can be calculated, if the battery VOLTAGE, and the circuit CURRENT are known.

Equation

$$\text{RESISTANCE} = \frac{\text{VOLTAGE}}{\text{CURRENT}} \qquad \boxed{R = \frac{E}{I}}$$

**EXAMPLE:** Calculate the opposition (ohms) of the resistor, which is limiting electron flow to 2 AMPERES.



$$R = \frac{E}{I} = \frac{10\ \text{VOLTS}}{2\ \text{AMPS}} = 5\ \text{OHMS}$$

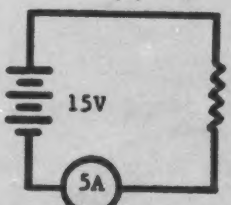
NOTE 1....If the opposition of the resistor was greater than 5 OHMS, the electron flow would NOT be as much as 2 AMPERES.

NOTE 2....If the opposition of the resistor was less than 5 OHMS, the current allowed to flow would have been greater than 2 AMPERES.

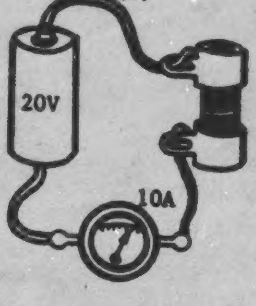
NOTE 3....Given a 10 VOLT battery, and a desired current of 2 AMPERES. The only resistor that can be used, is one having an opposition of 5 OHMS.

Q-8 Solve for the opposition of the resistors in the following circuits.

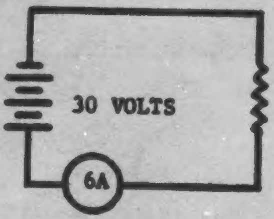
(a)



(b)



(c)



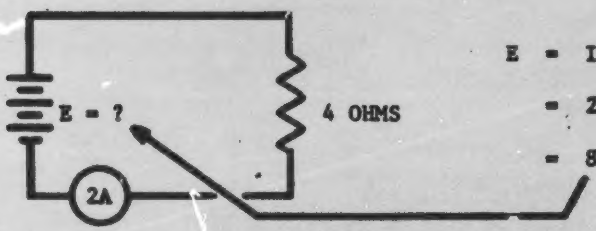
| A-7 | | |
|---|---|---|
| a. 4 AMPS | b. 2 AMPERES | c. 5A |

## VOLTAGE CALCULATION

The VOLTAGE of a battery can be calculated, if the opposition (ohms) of the resistor, and the circuit CURRENT are known.

*Equation* VOLTAGE = CURRENT · RESISTANCE $\boxed{E = I \cdot R}$

**EXAMPLE:** Calculate the battery VOLTAGE necessary to force an electron flow of 2 AMPERES thru a 4 OHM resistor.



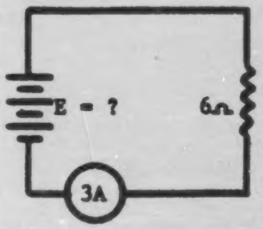
$E = I \cdot R$

$= 2A \cdot 4\Omega$

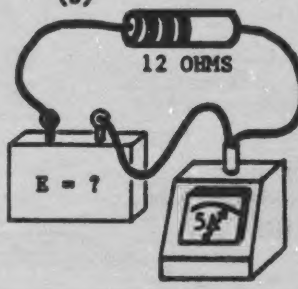
$= 8$ VOLTS

Q-9 Calculate the battery VOLTAGE in the following circuits.

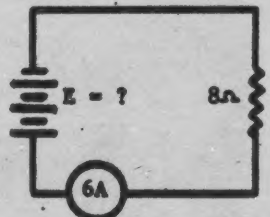
(a)



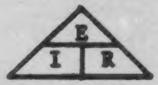
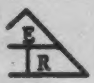
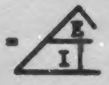
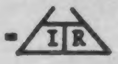
(b)



(c)



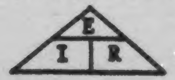
## THE OHMS LAW TRIANGLE

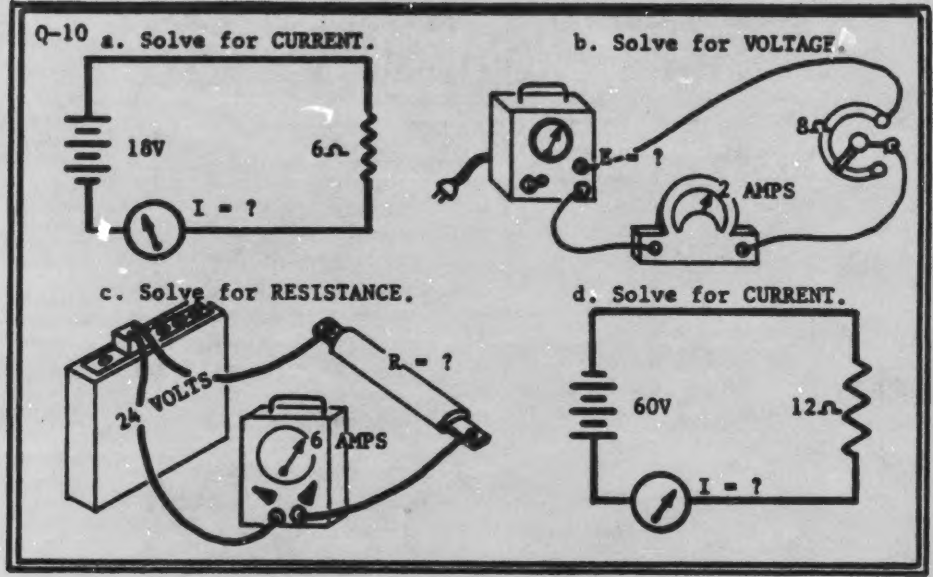
The 3 equations for RESISTANCE, CURRENT, and VOLTAGE can be formed into a "triangle".  The equation for "current" I =  The equation for "resistance"..... R =  The equation for "voltage" E =  These 3 equations will be used constantly, and the "Ohms Law Triangle" provides a ready reference for the proper formula.

A-8 a. 3 OHMS b. 2Ω c. 5Ω

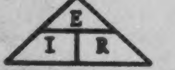
## CIRCUIT CALCULATIONS

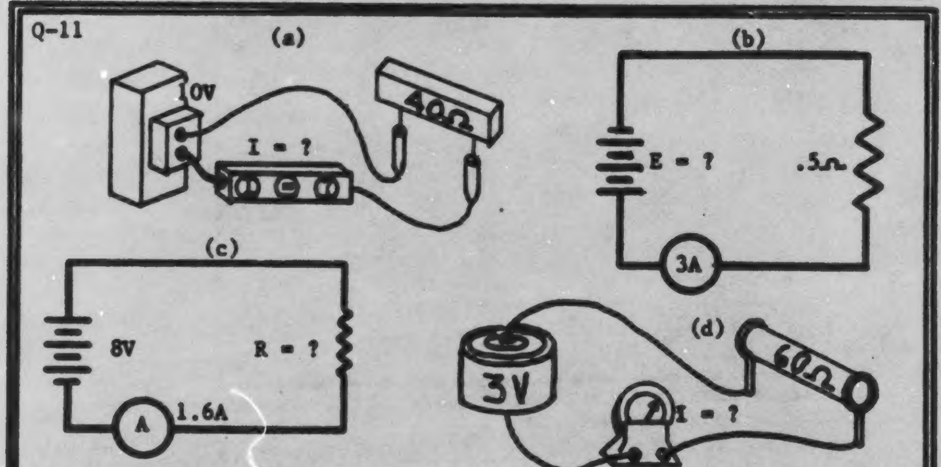
When solving the following circuit problems, first determine what is the question (E, I, or R). Then select the proper equation from the "Ohms Law Triangle", and solve.




Q-10 a. Solve for CURRENT.
b. Solve for VOLTAGE.
c. Solve for RESISTANCE.
d. Solve for CURRENT.

Watch the "decimal point" in the following circuits. Put the equation down, and be careful to enter the right values.





A-9 a. 18 VOLTS b. 60V c. 48V

KILO-OHMS and MILLI-AMPERES

Most "electronic" circuits operate on smaller amounts of current than the full AMPERE. Transistors and tubes function on the much smaller "milli-ampere" (Symbol mA ). One milli-ampere is only one-thousandth of a full AMPERE.

.001A = .001 ampere = 1 milli-ampere = 1mA
.005A = .005 ampere = 5 milli-amperes = 5mA
.009A = .009 ampere = 9 milli-amperes = 9mA
.01 A = .01 ampere = 10 milli-amperes = 10mA
.018A = .018 ampere = 18 milli-amperes = 18mA
.094A = .094 ampere = 94 milli-amperes = 94mA
.1 A = .1 ampere = 100 milli-amperes = 100mA
.102A = .102 ampere = 102 milli-amperes = 102mA
.158A = .158 ampere = 158 milli-amperes = 158mA
.64 A = .64 ampere = 640 milli-amperes = 640mA
.954A = .954 ampere = 954 milli-amperes = 954mA

1 full ampere = 1A = 1000 milli-amperes = 1000mA

To limit the circuit current to these smaller milli-ampere amounts, resistors with large opposition are used. These resistors are rated in KILO-OHMS. 1 KILO-OHMS equals 1000 OHMS.

500,000Ω = 500kΩ
400,000Ω = 400kΩ
350,000Ω = 350kΩ
100,000Ω = 100kΩ
95,000Ω = 95kΩ
22,000Ω = 22kΩ
8,000Ω = 8kΩ
6,500Ω = 6.5kΩ
5,000Ω = 5.0kΩ
4,230Ω = 4.23kΩ
2,350Ω = 2.35kΩ
1,200Ω = 1.2kΩ
1,150Ω = 1.15kΩ
1,060Ω = 1.06kΩ

.001kΩ = 1Ω
.002kΩ = 2Ω
.009kΩ = 9Ω
.01 kΩ = 10Ω
.012kΩ = 12Ω
.05 kΩ = 50Ω
.068kΩ = 68Ω
.099kΩ = 99Ω
.1 kΩ = 100Ω
.2 kΩ = 200Ω
.35 kΩ = 350Ω
.685kΩ = 685Ω
.952kΩ = 952Ω
1.0 kΩ = 1000Ω

Q-12 a. .002 amperes is the same as ________ milli-amperes.
b. .15 ampere is the same as __________ milli-amperes.
c. 250 milli-amperes is the same as ____________ ampere.
d. 25 milli-amperes is the same as ____________ ampere.
e. 1.3kΩ is the same as _________ ohms.
f. .02kΩ is the same as _________ ohms.

**A-10** a. 3A b. 16V c. 4Ω d. 5A

**A-11** a. .25A b. 1.5V c. 5Ω d. .05A

## PROBLEM SOLVING IN MILLI-AMPERES

When solving electronic circuit problems involving kilo-ohms, the answers for current will automatically come-out in milli-amperes.

**EXAMPLE:** $E = 10V$ $R = 2k\Omega$ $I = ?$ $I = \frac{E}{R} = \frac{10V}{2k\Omega} = 5\ mA$

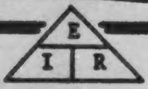
When solving circuit problems involving milli-amperes, the answers for resistance will automatically come-out in kilo-ohms.

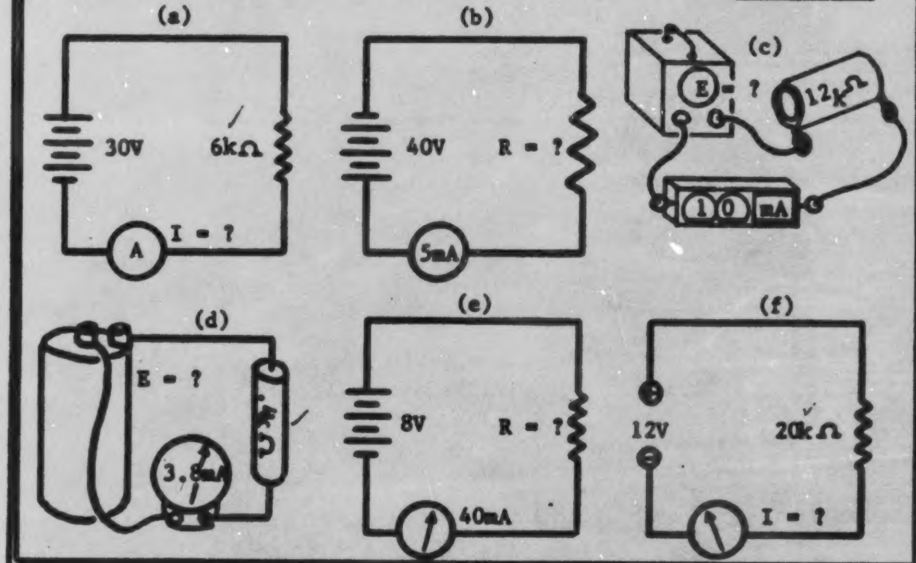
**EXAMPLE:** $E = 12V$ $I = 4mA$ $R = ?$ $R = \frac{E}{I} = \frac{12V}{4mA} = 3k\Omega$

When solving circuits with current in milli-amperes, and resistance in kilo-ohms, the voltage will come-out in unit VOLTS.

**EXAMPLE:** $I = 5mA$ $R = 4k\Omega$ $E = ?$ $E = I \cdot R$ $5mA \cdot 4k\Omega = 20V$

Q-13 Solve the following electronic circuits.





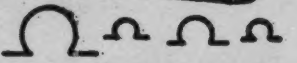
A-12
a. 2 milli-amperes
b. 150 milli-amperes
c. .25 ampere
d. .025 ampere
e. 1,300 ohms
f. 20 ohms

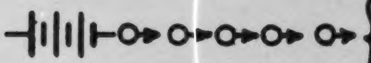
## OHMS LAW SUMMARY

The basic electrical circuit consists of

1. A source of power (battery)
2. Conductors (wire)
3. Current controlling device (resistor)

Different types of resistors are used to control the amount of current.

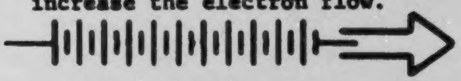


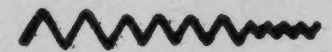


The level of voltage from the battery will also affect the amount of electron flow.

⊖ Electron flow (current) is from the "negative" terminal of the battery, thru the controlling device, and back into the "positive" terminal. ⊕

Increasing the battery voltage will increase the electron flow.

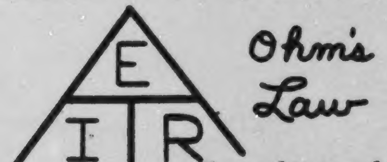




Reducing the opposition of the resistor, will allow more electron flow.

The electron flow (current) can be measured at any point in the electric circuit.

If the battery voltage, and the opposition of the resistor are known, the current can be calculated.



If the battery voltage, and the electron flow are known, the opposition of the resistor can be calculated.

The voltage of any battery can be determined by multiplying current times resistance.

When the resistance values are given in kilo-ohms, the electron flow will be in milli-amperes.

KΩ = (mA)

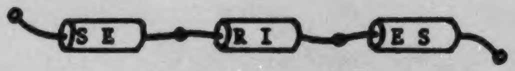
ΩVA KΩm

Ability to convert between milli, kilo, and units, is important to simplify circuit calculations.

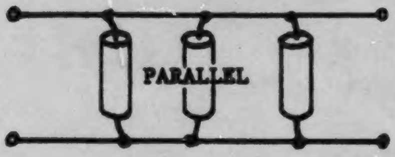
A-13
a. 5 milli-amperes (5mA)
b. 8 Kilo-ohms (8k Ω)
c. 120 volts (120V)
d. 1.52 volts (1.52V)
e. .2KΩ (200Ω)
f. .6mA (.0006A)

## SERIES RESISTIVE CIRCUITS

The connection of electrical components "end-to-end" is called, "connecting them in SERIES".

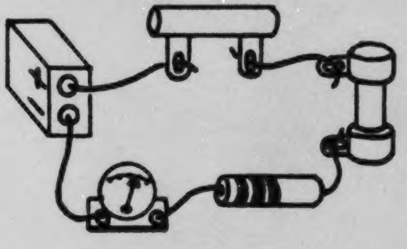


The connection of these same components "side-by-side", is called, "connecting them in PARALLEL.

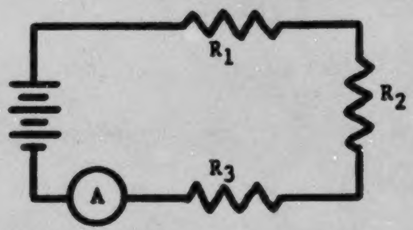


Only the SERIES connection will be discussed at this time. Parallel circuits will come later.

SERIES RESISTIVE CIRCUIT

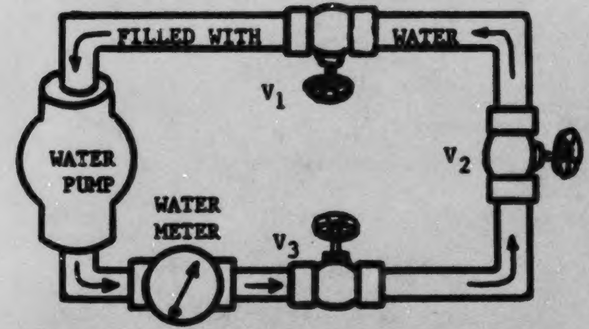


SCHEMATIC



No matter which way current is flowing, the resistors are usually numbered in a "clockwise" direction as $R_1$, $R_2$, $R_3$ etc.. Before going any furthur, it might be best to study the "hydraulic analogy".

## HYDRAULIC ANALOGY



The important thing to observe here, is that each valve will have some effect on the flow of water thru the entire system.

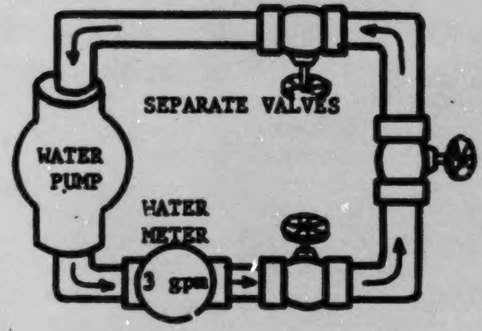
Stay here a minute, and try to imagine actually adjusting each valve. What are the effects on the water meter reading?

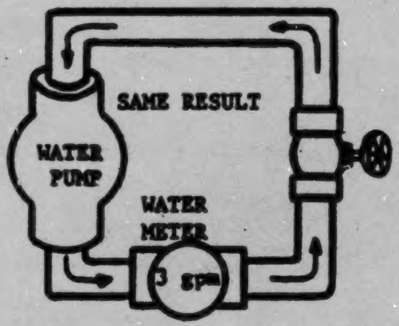
Q-14 a. "End-to-end" connection, is called a ________ connection.
b. "Side-by-side" connection, is called a ________ connection.

## HYDRAULIC ANALOGY (cont)

Suppose the flow of water is to be restricted to 3 gallons per minute. Are three separate valves required?.......The answer is NO!

The three valves could be replaced with one valve, opened enough to allow 3 gallons per minute to flow thru it.

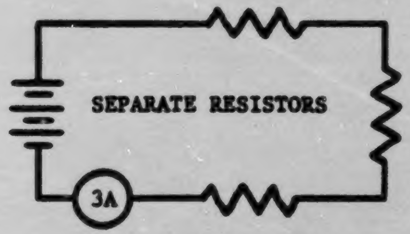


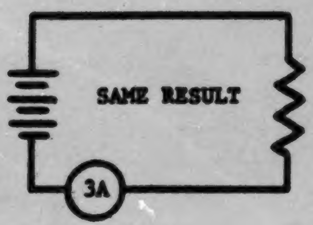


## ELECTRIC CIRCUIT

Suppose the flow of electrons is to be limited to 3 amperes. Are three separate resistors required?............The answer is NO!

The three resistors could be replaced with one resistor, having enough opposition (ohms) to restrict current to 3 amperes.





## WHY USE THREE RESISTORS, INSTEAD OF ONE?

Series circuits, with more than one resistor, are capable of providing many different "voltages" from one battery source. These voltages can then be used to operate other parts of complex electronic circuits. How this is done, will be covered later in the text.

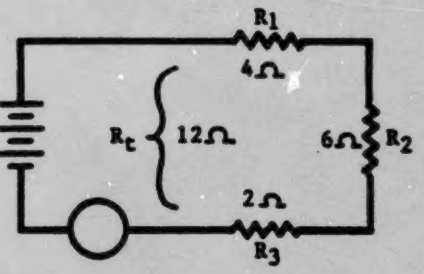
Q-15 a. Water is controlled by the "number" of valves in the system. (True or False.......be careful!)
b. Current is controlled by the "number" of resistors in the circuit. (True or False.......again, think!)

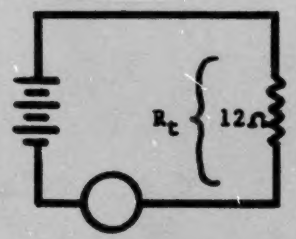
A-14

a. "series" b. "parallel"

## SERIES CIRCUIT TOTAL RESISTANCE

The "total opposition" to the flow of current, is called........ TOTAL RESISTANCE (Symbol $R_t$). It is the "sum" of all the individual resistances. It is the one resistor that can be used in place of the separate resistors. Current is limited by the TOTAL RESISTANCE ($R_t$).

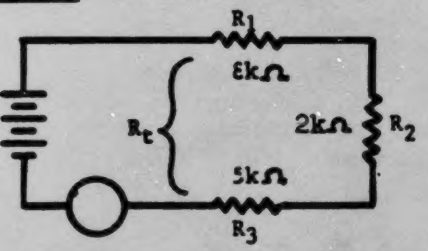




Equation In equation form this would be $\boxed{R_t = R_1 + R_2 + R_3}$

NOTE: If the resistances are given in kilo-ohms, "drop" the K, add the numbers, and put K back on the answer.

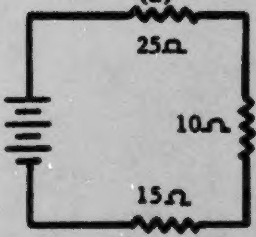
EXAMPLE: Calculate the Total Resistance ($R_t$) of this circuit.



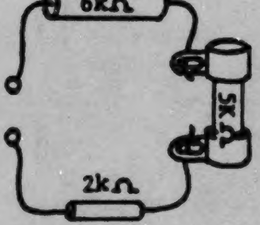
$$R_t = R_1 + R_2 + R_3$$
$$= 8 + 2 + 5$$
$$= 15k\Omega$$

Q-16 Calculate the Total Resistance ($R_t$) of these circuits.

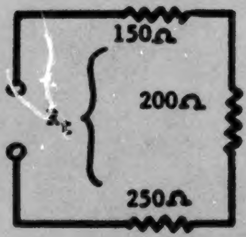
(a)



(b)



(c)



A-15 a. False...the flow is not controlled by the "number" of valves. It is controlled by the "settings" of the valves.

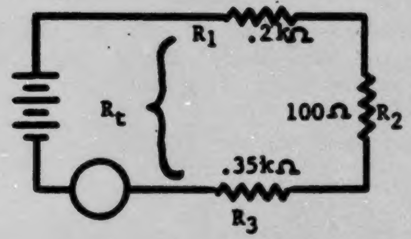
b. False...one resistor can "control" the same as five.

**TOTAL RESISTANCE (cont)**

The ability to rapidly and easily convert resistance values in ohms and kilo-ohms is important. It simplifies circuit calculations, and results in a higher level of accuracy.

The following circuits, have resistances in ohms and kilo-ohms mixed-up. Solve for total resistance ($R_t$), by converting all the resistor values to either ohms, or kilo-ohms, then add. Provide the answers both ways (ohms and kilo-ohms).

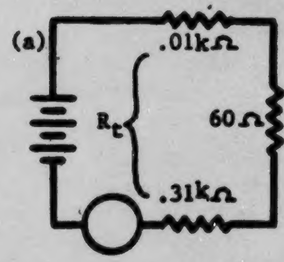
**EXAMPLE:** Solve for Total Resistance ($R_t$) in ohms and kilo-ohms.

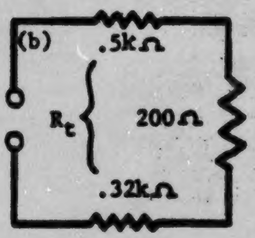


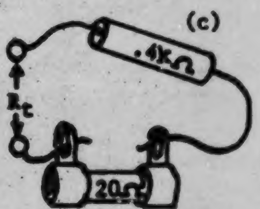
.2kΩ = 200Ω
100Ω = 100Ω
.35kΩ = 350Ω

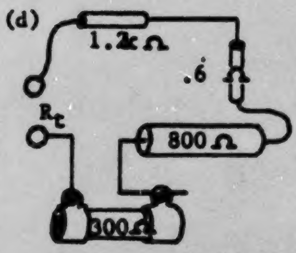
$R_t$ = $R_1$ + $R_2$ + $R_3$
= 200 + 100 + 350
= 650Ω = .65kΩ

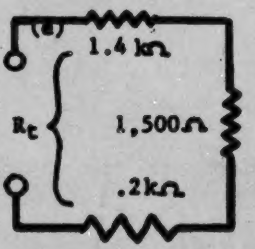
Q-17 Solve for Total Resistance ($R_t$) in ohms and kilo-ohms.

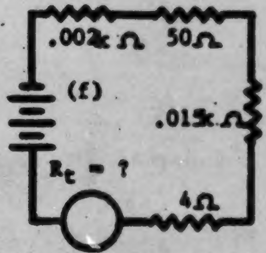












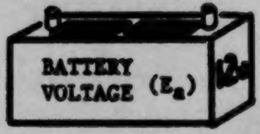
A-16 a. 50Ω b. 13kΩ c. 600Ω

## THE APPLIED VOLTAGE

As the battery is the source of power "applied" to the circuit, it will now take-on a new name.....the APPLIED VOLTAGE (Symbol $E_a$).

Soon, there will be other "voltages" within the series circuit, and the "Applied Voltage" ($E_a$) must be kept separate from them.

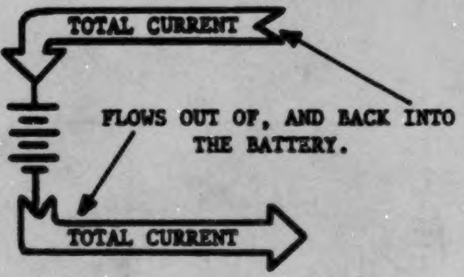
*Applied Voltage* =



## THE TOTAL CURRENT

Until now, the electron flow thru the circuit was referred to as simply the "current (I)". It will now take-on a new name ........the TOTAL CURRENT (Symbol $I_t$). Often in electronic circuits, there is more than one "current" flowing, and these must be kept separate from the Total Current ($I_t$). Only the Total Current ($I_t$) flows out of, and back into the battery.

*Total ($I_t$) Current*



## THE TOTAL RESISTANCE (Review)

The total opposition to the flow of electrical current is called the TOTAL RESISTANCE ($R_t$). It limits the amount of electron flow, out of, and back into the battery. It controls Total Current ($I_t$).

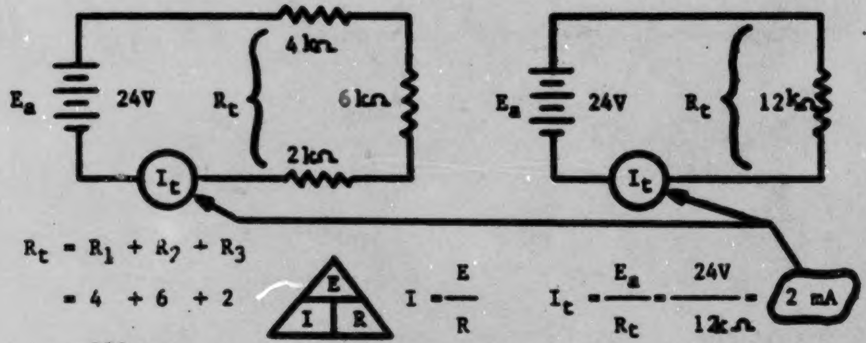
Q-18 a. The voltage produced by any power source is referred to as the ________________ voltage.
b. The total opposition to the flow of electrons, is called ________________ resistance.

A-17

a. 380Ω (.38kΩ)
b. 1,020Ω (1.02kΩ)
c. 420Ω (.42kΩ)
d. 2,900Ω (2.9kΩ)
e. 3,100Ω (3.1kΩ)
f. 71Ω (.071kΩ)

## CALCULATING TOTAL CURRENT ($I_t$)

Following the calculation for Total Resistance ($R_t$), the amount of Total Current ($I_t$) flowing is determined using Ohms Law.



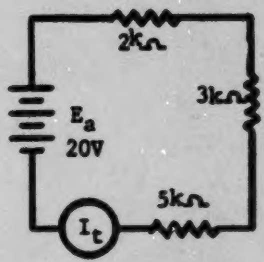
$R_t = R_1 + R_2 + R_3$
$= 4 + 6 + 2$
$= 12k\Omega$

$I = \frac{E}{R}$

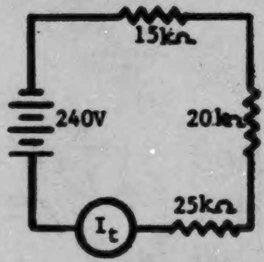
$I_t = \frac{E_a}{R_t} = \frac{24V}{12k\Omega} = 2\ mA$

Q-19 Calculate the Total Current ($I_t$) in the following circuits. Give answers both in Amperes and milli-amperes.

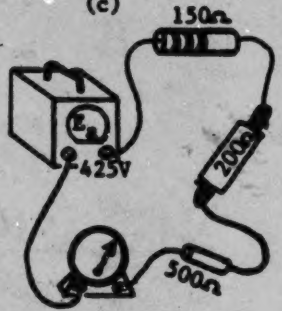
(a)



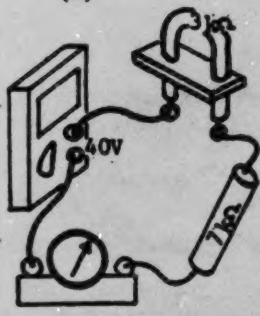
(b)



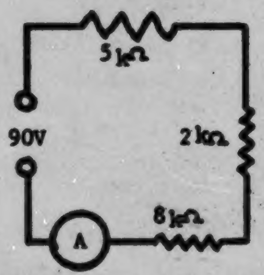
(c)



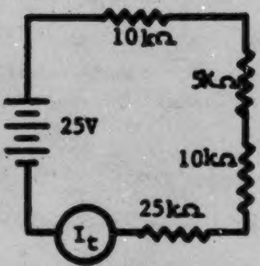
(d)



(e)



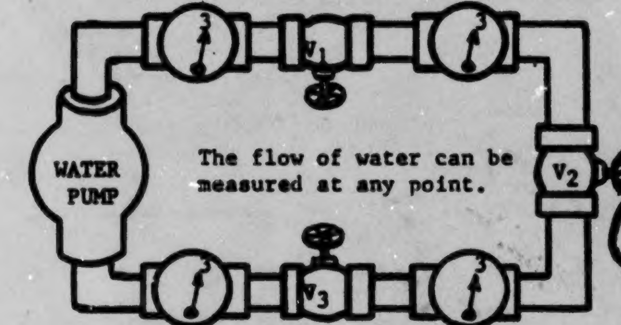
(f)



A-18 a. applied voltage..... it is the electromotive force, applied to the circuit, and it will force electrons to flow thru the circuit.
b. total resistance ($R_t$)....the total opposition.

MEASURING TOTAL CURRENT ($I_t$)

Although the Total Current ($I_t$) is described as: "the current flowing out of, and back into the battery", it can be measured at any point in a Series Circuit. No matter where the current is measured, the readings will all be the same. Observe the "hydraulic analogy"...

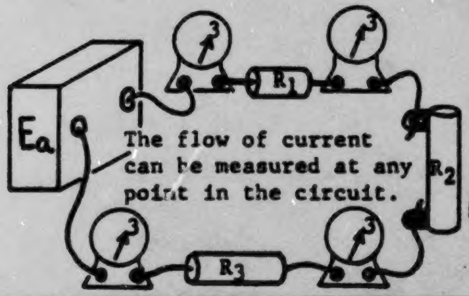


The flow of water can be measured at any point.

The amount of water "moving" is the same at any point in the system. Therefore, the "flow" can be measured anywhere.

THE ELECTRIC CIRCUIT

The flow of electrons thru a Series Circuit, can be measured at any point. An ampere-meter reading, anywhere in the circuit, is a measurement of the Total Current ($I_t$). This is NOT true of all electronic circuits, but it IS an important point in Series Circuits.



The flow of current can be measured at any point in the circuit.

The amount of electrons "moving", is the same at any point in the circuit, Therefore, the "flow" can be measured anywhere.

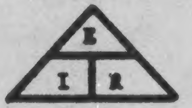
Q-20 a. The current flowing out-of, and back-into the battery is called the ____________ current.
b. T-F The amount of total current flowing, can be measured at only ONE point.
c. Would it be possible for two ammeters in a Series Circuit to have different readings? (Yes-No)

A-19

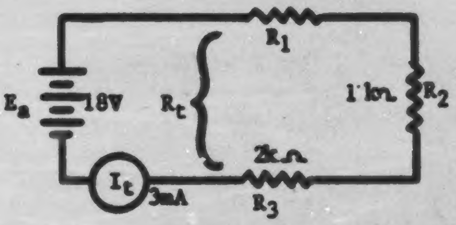
| | | | |
|---|---|---|---|
| a. | 2mA (.002A) | d. | 4mA (.004A) |
| b. | 4mA (.004A) | e. | 6mA (.006A) |
| c. | .5A (500mA) | f. | .5mA (.0005A) |

## CALCULATING TOTAL RESISTANCE

If the Applied Voltage ($E_a$) and the Total Current ($I_t$) are known, the Total Resistance ($R_t$) can be determined using Ohms Law. It is NOT necessary to know the resistance of each resistor.



**EXAMPLE:** Determine the Total Resistance ($R_t$) and $R_1$.

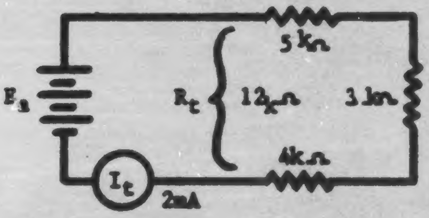


$$R = \frac{E}{I} \qquad R_t = \frac{E_a}{I_t} = \frac{18V}{3mA} = 6k\Omega$$

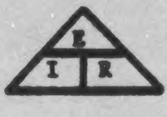
Since the Total Resistance ($R_t$) = 6kΩ, then by subtraction, $R_1$ must be 3kΩ.

## CALCULATING THE APPLIED VOLTAGE

If the Total Resistance ($R_t$), and the Total Current ($I_t$) are known, the Applied Voltage ($E_a$) can be determined using Ohms Law.



$$E = I \cdot R \qquad E_a = I_t \cdot R_t$$

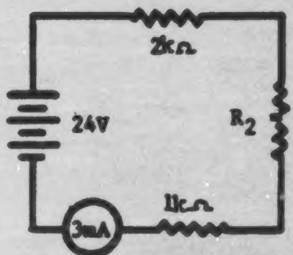


$$= 2mA \cdot 12k\Omega$$

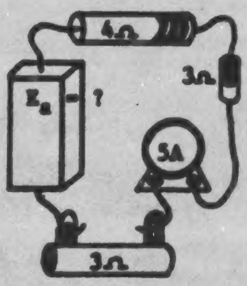
$$= 24V$$

Q-21 Solve for the indicated missing voltage or resistance.

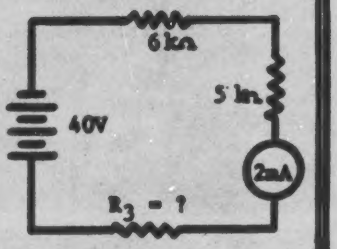
(a)



(b)



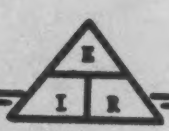
(c)



A-20
- a. total current ($I_t$)
- b. False....it can be measured at any number of points.
- c. No....if two ammeters have different readings, one of the meters is broken.

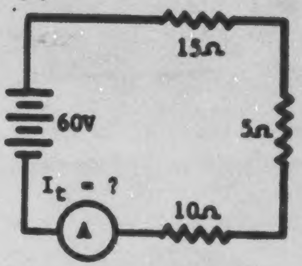
## PRACTICE PROBLEMS

Test your skills in Series Circuits with the problems which follow. The first step is to make sure of the "question". Then form a "plan of attack" toward the solution.

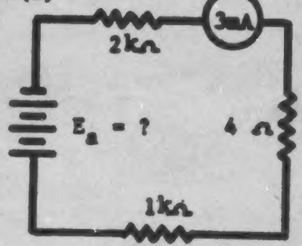


Q-22 Solve as indicated.

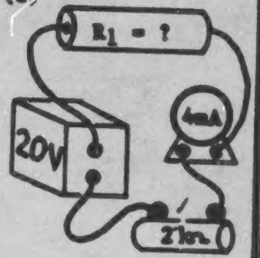
(a)



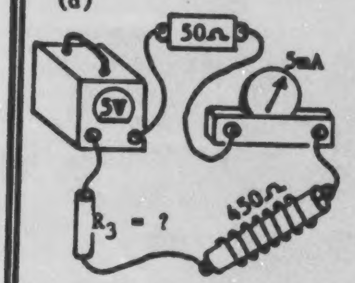
(b)



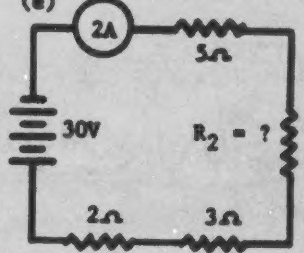
(c)



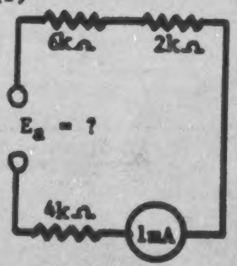
(d)



(e)

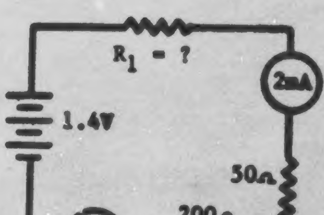


(f)

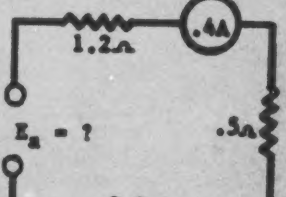


NOTE: Be careful of the decimal point in the following problems.

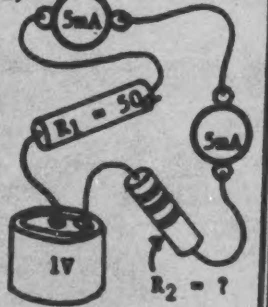
(g)



(h)



(i)



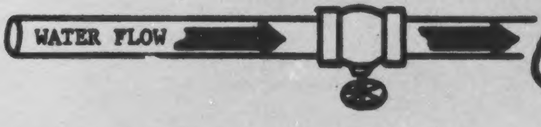
A-21

a. 5k ($R_t$ = 8k$\Omega$)  b. 50V ($R_t$ = 10$\Omega$)  c. 9k ($R_t$ = 20k$\Omega$)

## VOLTAGE DROPS

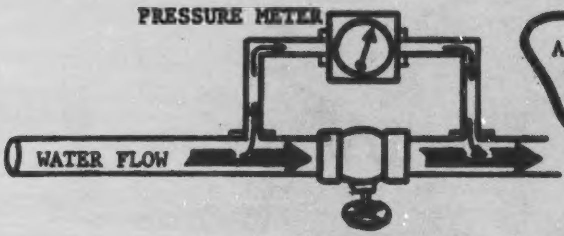
If the two leads of a voltmeter are placed on opposite sides of a resistor (in an operating Series Circuit), the meter will indicate a particular "voltage" reading. This voltage reading is referred to as the resistor's "voltage drop".

To better see this, refer to the "hydraulic analogy" for a moment.



This is one of the valves, in a complete water system.

Due to the valve there is a "pressure drop", which can be measured by connecting a "pressure meter" across the valve.



A small amount of the water is forced to flow thru the "pressure meter".

The reading on the pressure meter is determined by how much water is forced to flow thru it. This of course, depends upon the force of the "oncoming water", and the opposition (setting) of the valve.

## PRESSURE DROP.....ADDITION

If the "pressure drops" across all of the valves in the system are added together, the answer will be equal to the pump pressure.

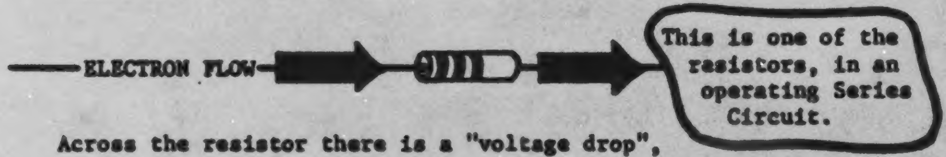
Q-23 a. The voltage measured across a resistor (in an operating circuit), is called a voltage __________.
b. T-F To measure a "voltage drop", the leads of a voltmeter must be placed on the same side of the resistor.
c. In a hydraulic system, if all the "pressure drops" are added together, the answer is equal to the _____ pressure.

| | | | |
|---|---|---|---|
| A-22 | a. 2A | d. 500$\Omega$ ($R_t$=1k) | g. 450$\Omega$ ($R_t$= .7k) |
| | b. 21V | e. 5$\Omega$ | h. 1.6V |
| | c. 3k$\Omega$ | f. 12V | i. 150$\Omega$ ($R_t$=.2k) |

## RESISTOR VOLTAGE DROP

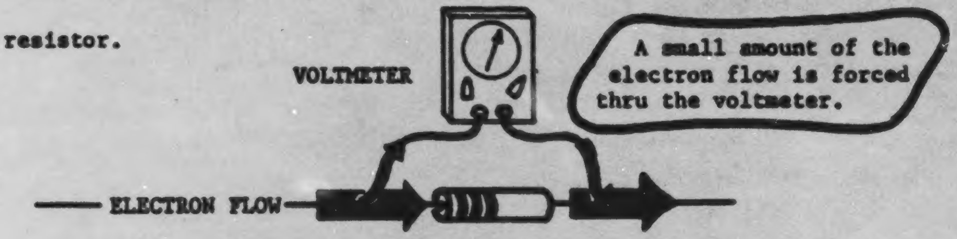
The voltage measured across a resistor (by a voltmeter), is called ......that resistor's "voltage drop".

Assume the flow of electrons thru a resistor....



This is one of the resistors, in an operating Series Circuit.

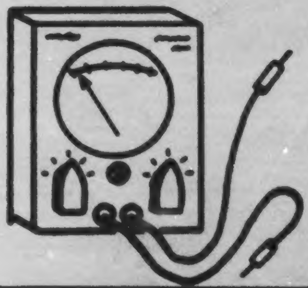
Across the resistor there is a "voltage drop", which can be measured by connecting a "voltmeter" in parallel with the resistor.



A small amount of the electron flow is forced thru the voltmeter.

The reading on the voltmeter is determined by how much of the electron flow is forced thru it. This of course, depends upon the force of the "oncoming electron flow", and the opposition of the resistor.

### VOLTMETERS

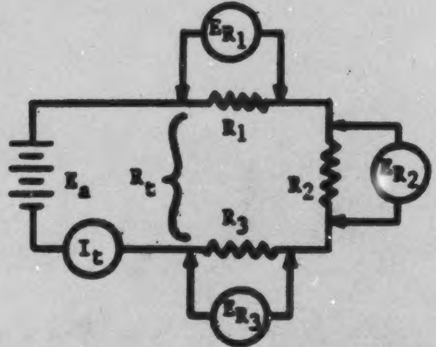


A voltmeter is a "high resistance device". It requires only a very small flow of electrons (thru it), to produce a reading. Most of the time, this small electron flow is only a few "micro-amperes", and it does NOT "upset" the actual circuit current.

Q-24 a. T-F To measure a voltage drop, the voltmeter is placed in "series" with the resistor.
b. T-F A voltmeter is a high resistance device.
c. If the current thru a resistor becomes greater, the voltage drop created across it will ____________ (inc or dec).

A-23 a. drop
b. false....the two leads of the voltmeter must be placed on "opposite" sides of the resistor. Both leads on the same side, would give a "zero" reading.
c. pump pressure.

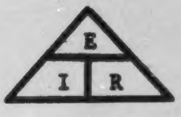
## CALCULATING VOLTAGE DROPS



The voltage drops across each resistor in a Series Circuit, are labeled $E_{R_1}$, $E_{R_2}$, $E_{R_3}$ etc..

### Equations

The amount of voltage drop across each resistor, can be calculated using Ohms Law.



$$E = I \cdot R$$

$$E_{R_1} = I_{R_1} \cdot R_1$$

$$E_{R_2} = I_{R_2} \cdot R_2$$

$$E_{R_3} = I_{R_3} \cdot R_3$$

In a Series Circuit, there is only ONE current, the Total Current ($I_t$). Therefore the current thru $R_1$ ($I_{R_1}$), the current thru $R_2$ ($I_{R_2}$), and the current thru $R_3$ ($I_{R_3}$), are all the same, and equal to whatever the Total Current ($I_t$) actually is.

## KIRCHOFF'S VOLTAGE LAW

One of the most important electric laws, is Kirchoff's Voltage Law. It states (in effect): All of the voltage drops added together will equal the battery voltage.

### Equation

KIRCHOFF'S VOLTAGE LAW

$$E_a = E_{R_1} + E_{R_2} + E_{R_3} \text{ etc.}$$

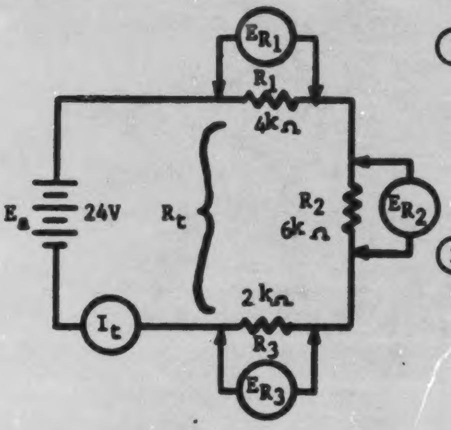
Q-25 a. T-F A voltage drop is created whenever current flows thru a resistor.
b. T-F Kirchoff's Law, is the same as Ohm's Law.

A-24
a. False....the meter must be placed in "parallel" with the resistor. In "series" the high resistance of the voltmeter would stop the flow of current.
b. True....the "higher", the "better".
c. True....due to the greater force of the electron flow.

CALCULATING VOLTAGE DROPS (cont)

To calculate the voltage drops across each resistor, multiply the circuit current ($I_t$) times the resistance (ohms) of each resistor.

EXAMPLE: Determine the voltage drop across each resistor.



① Calculate the Total Resistance ($R_t$)

$$R_t = R_1 + R_2 + R_3$$
$$= 4k\Omega + 6k\Omega + 2k\Omega$$
$$= 12k\Omega$$

② Calculate the Total Current ($I_t$)

$$I_t = \frac{E_a}{R_t} = \frac{24V}{12k\Omega} = 2mA$$

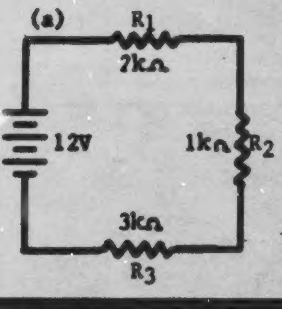
③ Multiply the current, times each resistor.

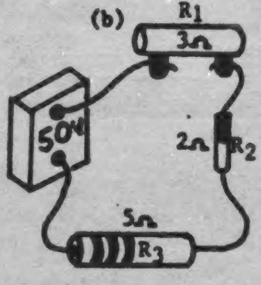
$$E_{R_1} = I_{R_1} \cdot R_1 = 2mA \cdot 4k\Omega = 8V$$
$$E_{R_2} = I_{R_2} \cdot R_2 = 2mA \cdot 6k\Omega = 12V$$
$$E_{R_3} = I_{R_3} \cdot R_3 = 2mA \cdot 2k\Omega = 4V$$

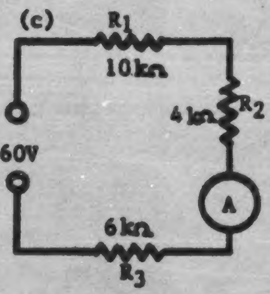
④ Use Kirchoff's Voltage Law, to "check" the work.

$$E_a = E_{R_1} + E_{R_2} + E_{R_3}$$
$$= 8V + 12V + 4V$$
$$= \underline{\underline{24V}} = \underline{\underline{\text{Battery Voltage}}}$$

Q-26 Calculate each resistor voltage drop, in the circuits below.



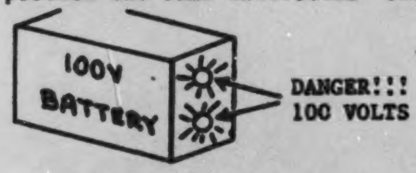


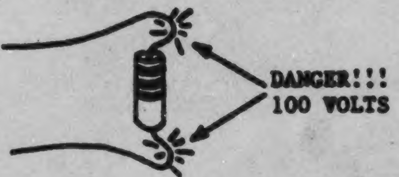


A-25 a. True....and these voltage drops are very useful.
b. False....Ohm's Law deals with the flow of current. Kirchoff's Law deals with "the sum of the voltage drops".

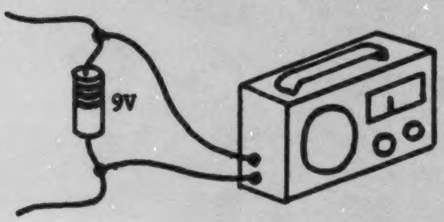
USE OF VOLTAGE DROPS

The "voltage drop" appearing across any resistor, will create the same effects as the voltage from a battery. A 100V "voltage drop" will produce the same electrical "shock" as a 100 volt battery.





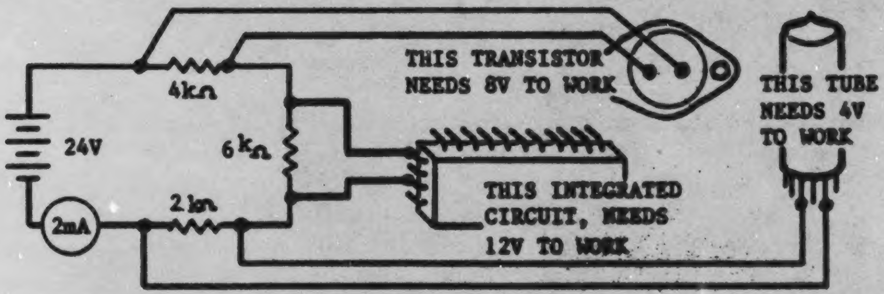
The voltage drop across a resistor can be used to operate a transistor radio, in place of the regular battery.



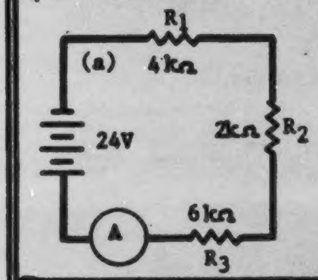
DO NOT DAMAGE YOUR RADIO!!!

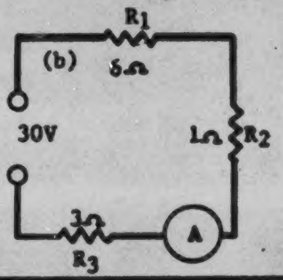
Some other special circuit considerations must be met before substituting a voltage drop in place of the normal battery required.

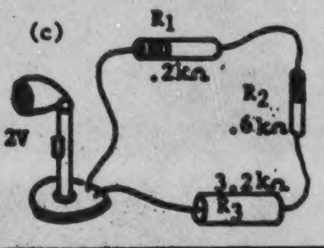
The "voltage drops" obtained across resistors are used to provide the "operating voltages" for other electrical components.


4kΩ
THIS TRANSISTOR NEEDS 8V TO WORK
THIS TUBE NEEDS 4V TO WORK
24V
6kΩ
THIS INTEGRATED CIRCUIT, NEEDS 12V TO WORK
2kΩ
2mA

Q-27 Calculate each resistor voltage drop, in the circuits below.



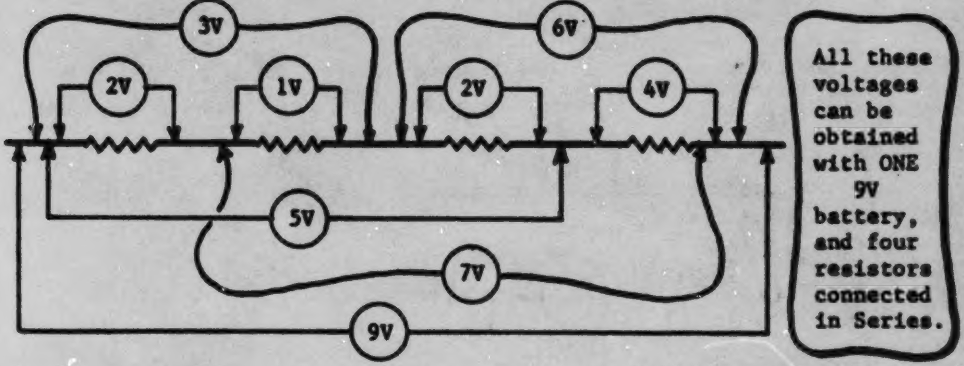




| A-26 | a. | b. | c. |
|---|---|---|---|
| | $E_{R_1} = 4V$ | $E_{R_1} = 15V$ | $E_{R_1} = 30V$ |
| | $E_{R_2} = 2V$ | $E_{R_2} = 10V$ | $E_{R_2} = 12V$ |
| | $E_{R_3} = 6V$ | $E_{R_3} = 25V$ | $E_{R_3} = 18V$ |

## COMBINING VOLTAGE DROPS

The voltage drops across two or more separate resistors, can be combined together to form additional voltage variations. EXAMPLE:

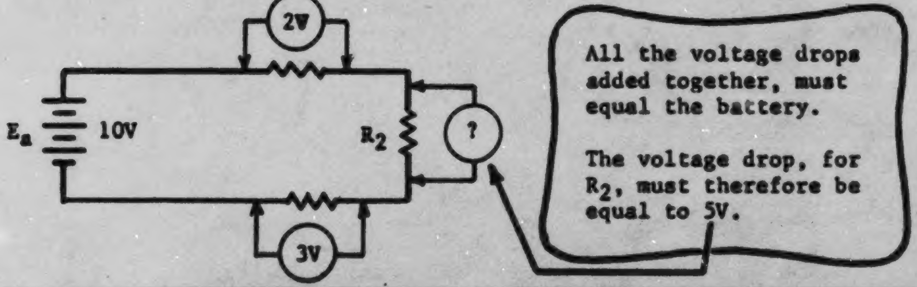


All these voltages can be obtained with ONE 9V battery, and four resistors connected in Series.

## USING KIRCHOFF'S LAW

"The sum of the voltage drops equals the applied voltage ($E_a$)". If one of the resistor voltage drops is not indicated, it may be determined thru "subtraction".

EXAMPLE: What is the voltage drop across $R_2$?



All the voltage drops added together, must equal the battery.

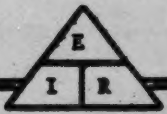
The voltage drop, for $R_2$, must therefore be equal to 5V.

Q-28 a. T-F The voltage dropped across a resistor, can be calculated using Kirchoff's Law.
b. Kirchoff's Law states: "The sum of the voltage drops, equals the ____________________ voltage".
c. T-F Two voltage drops can be combined together, to form a third "usable" voltage.
d. T-F If the current flowing thru a resistor increases, the voltage drop across it will increase.

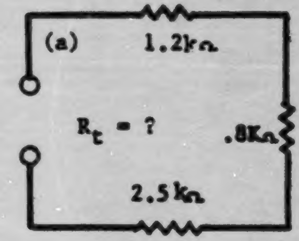
| A-27 | a. | b. | c. |
|---|---|---|---|
| | $E_{R_1} = 8V$ | $E_{R_1} = 18V$ | $E_{R_1} = .1V$ |
| | $E_{R_2} = 4V$ | $E_{R_2} = 3V$ | $E_{R_2} = .3V$ |
| | $E_{R_3} = 12V$ | $E_{R_3} = 9V$ | $E_{R_3} = 1.6V$ |

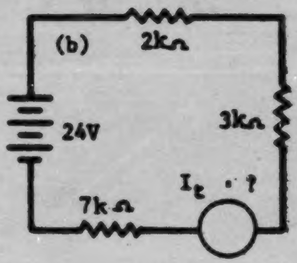
**PRACTICE PROBLEMS**

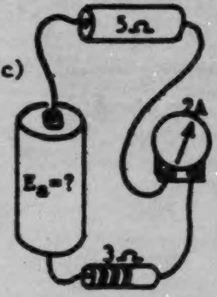
Test your skills in Series Circuits with the problems which follow. The first step is to make sure of the "question". Then form a "plan of attack" toward the solution.

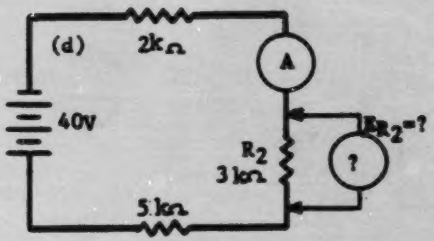


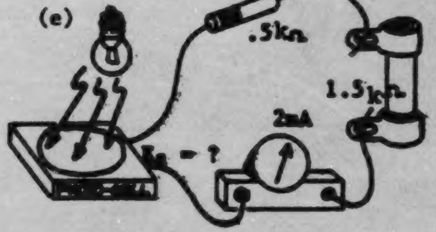
Q-29 Solve as indicated.

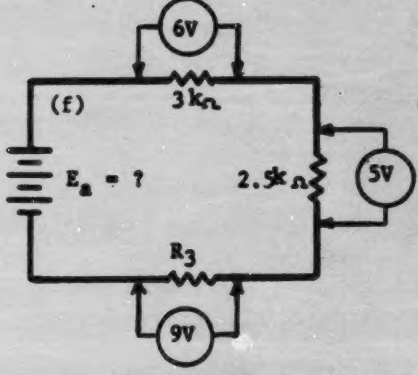


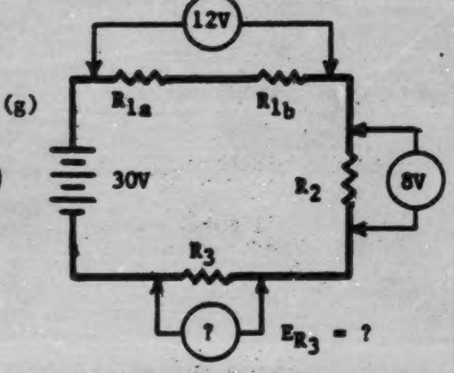










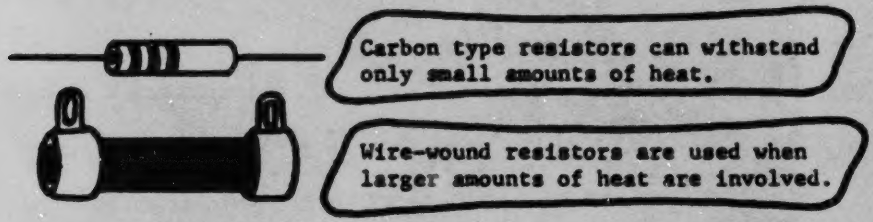


A-28 a. True....thru "subtraction". Using Ohm's Law, it can be determined using "multiplication" ($E = I \cdot R$).
b. Applied Voltage ($E_a$)
c. True....and this is often done in electronic circuits.
d. True....the increase of current can be caused by a bigger battery, or the reduction of opposition of another resistor.

## ELECTRICAL POWER

The flow of electrons thru some type of opposition, produces heat. When electrical current flows thru a light-bulb, heat is generated. Soldering-irons depend upon this conversion of electrical energy into heat. The resistance wire, used in electric-toasters, is heated by the flow of large quantities of electrons.

Of course, resistors offer opposition to electrical current, and heat will be generated within them. With proper physical construction, the heat produced will not damage the resistors. However, this heat must be "gotten-rid-of" into the surrounding air. If not, the heat will continue to "build-up", until the resistor is damaged.



Carbon type resistors can withstand only small amounts of heat.

Wire-wound resistors are used when larger amounts of heat are involved.

The "physical size" of a resistor (its surface area), is the main factor which determines how much heat it can "dissipate" (get-rid-of). Therefore, carbon and wire-wound resistors have many different shapes and sizes. It is important to understand that the "physical size", has nothing to do with the resistance (ohms) of a resistor. The resistance depends upon the materials used "inside" the resistor.

Q-30 a. The flow of electrons thru an opposition, produces ________.
b. To "dissipate", means to ____________________.
c. T-F Carbon resistors are used to dissipate large amounts of heat.
d. T-F The heat, dissipated by a resistor in a radio, is useful to the operation of the radio.

**A-29**

a. 4.5kΩ
b. 2mA
c. 16V
d. 12V
e. 4V
f. 20V
g. 10V

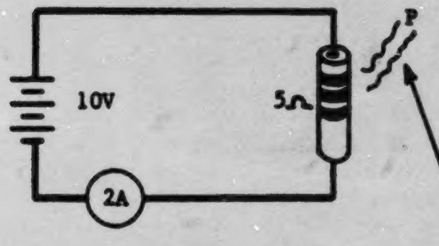
## ELECTRICAL POWER (cont)

The symbol used for the word POWER is P, and the unit of measure for electrical power is the WATT (Symbol W).

As might be expected, the heat generated within a resistor, depends upon the amount of CURRENT (I), and the RESISTANCE (R) of the resistor.

Equation POWER (HEAT) = CURRENT$^2$ · RESISTANCE

This basic POWER equation indicates that the CURRENT must be "squared", before multiplying it times the RESISTANCE.



$$\begin{aligned} P &= I^2 \cdot R \\ &= 2^2 \cdot 5 \\ &= 4 \cdot 5 \\ &= 20 \text{ WATTS (20W)} \end{aligned}$$

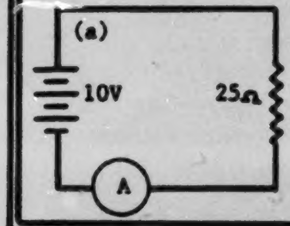
There are two other POWER equations which could have been used, to obtain the same answer.

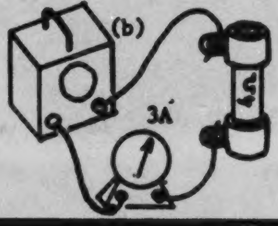
$$P = \frac{E^2}{R} = \frac{10^2}{5} = \frac{100}{5} = 20 \text{ WATTS (20W)}$$

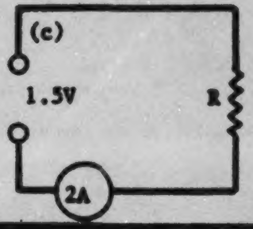
$$\begin{aligned} P &= E \cdot I \\ &= 10 \cdot 2 \\ &= 20 \text{ WATTS (20W)} \end{aligned}$$

Since there are three POWER equations which can be used to obtain the same answer, use the one which is the easiest, depending upon "what" is given in the problem.

**Q-31** Calculate the POWER dissipated by these resistors.







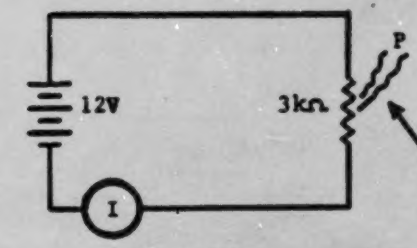
A-30
- a. heat....sometimes useful, sometimes wasted.
- b. eliminate, or get-rid-of.
- c. False...large amounts of heat would damage a carbon type.
- d. False...the heat is wasted, and is considered a "loss of energy".

## WATTS AND MILLI-WATTS

When the resistance values are given in unit OHMS, the circuit current will be in unit AMPERES. Under these conditions, the POWER calculations come-out in unit WATTS.

However, when the resistance values are given in KILO-OHMS, the flow of current is limited to the smaller MILLI-AMPERE. With this reduction in the flow of electrons, the heat generated within the resistors will be much smaller. When the current is measured in MILLI-AMPERES (mA), the power calculations will come-out in the smaller MILLI-WATT (mW). An example follows......

EXAMPLE: Calculate the power dissipated by the resistor.



① $I = \frac{E}{R} = \frac{12V}{3k\Omega} = 4mA$

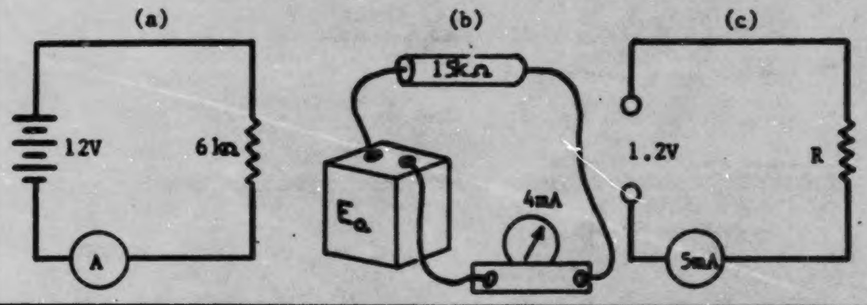
② $P = I^2 \cdot R$

$= 4^2 \cdot 3$

$= 16 \cdot 3$

$= 48$ milli-watts (48mW)

Q-32 Calculate the power dissipated by the resistors in the follow- circuits. Give answers in BOTH watts AND milli-watts.



A-31

**a. 4 WATTS (4W)** **b. 36 WATTS (36W)** **c. 3 WATTS (3W)**

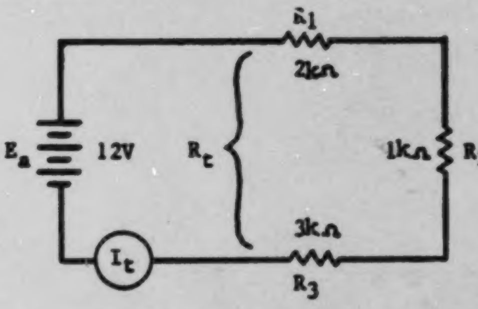
**TOTAL POWER**

When there is more than ONE resistor in a circuit, the total power generated by them must be calculated. This is called....calculating the TOTAL POWER (Symbol $P_t$ ).

To determine the Total Power ($P_t$), calculate the power dissipated by each individual resistor, then ADD.

Equation TOTAL POWER ($P_t$) = $P_{R_1} + P_{R_2} + P_{R_3}$ etc.

EXAMPLE: Calculate the Total Power ($P_t$)



① $R_t = R_1 + R_2 + R_3$

$= 2k\Omega + 1k\Omega + 3k\Omega$

$= 6k\Omega$

② $I_t = \dfrac{E_a}{R_t} = \dfrac{12V}{6k\Omega} = 2mA$

③ $P_{R_1} = I_{R_1}^{\;2} \cdot R_1$

$= 2^2 \cdot 2$

$= 4 \cdot 2$

= 8 milli-watts

④ $P_{R_2} = I_{R_2}^{\;2} \cdot R_2$

$= 2^2 \cdot 1$

$= 4 \cdot 1$

= 4 milli-watts

⑤ $P_{R_3} = I_{R_3}^{\;2} \cdot R_3$

$= 2^2 \cdot 3$

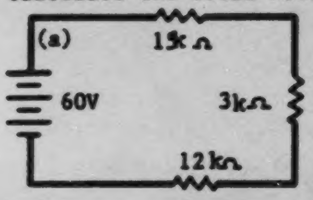
$= 4 \cdot 3$

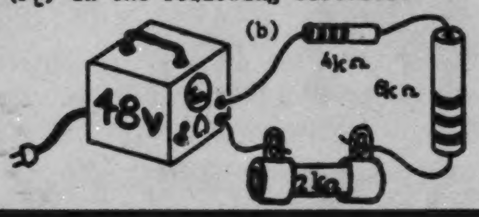
= 12 milli-watts

⑥ $\boxed{P_t = P_{R_1} + P_{R_2} + P_{R_3}} = 8mW + 4mW + 12mW = 24mW$

TOTAL POWER

Q-33 Calculate the Total Power ($P_t$) in the following circuits.





A-32

- a. 24 milli-watts (24mW) .024 watts (.024W)
- b. 240 milli-watts (240mW) .24 watts (.24W)
- c. 6 milli-watts (6mW) .006 watts (.006W)

## TOTAL POWER (cont)

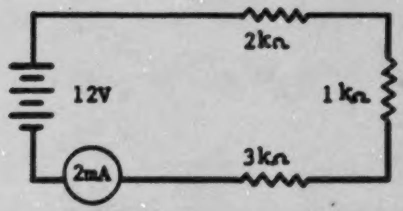
Several other methods can be used, to calculate the Total Power ($P_t$). The "totals" of Resistance ($R_t$), Current ($I_t$) and Voltage ($E_a$) may be used.

Equations

$$\boxed{P_t = E_a \cdot I_t} \quad \boxed{P_t = \frac{E_a^2}{R_t}} \quad \boxed{P_t = I_t^2 \cdot R_t}$$

It is NOT necessary to determine the power dissipated by every resistor in the circuit, to calculate the Total Power ($P_t$). In complex circuits, this would be difficult and time-consuming.

**EXAMPLE:** Calculate the Total Power ($P_t$) in the following circuit.



$E_a = 12V$

$I_t = 2mA$

$R_t = 6k\Omega$

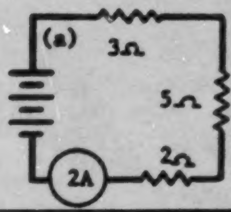
$$P_t = E_a \cdot I_t = 12V \cdot 2mA = 24mW$$

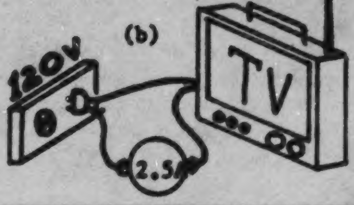
$$P_t = \frac{E_a^2}{R_t} = \frac{12V^2}{6k\Omega} = \frac{144}{6} = 24mW$$

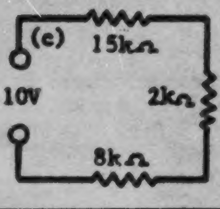
$$P_t = I_t^2 \cdot R_t = 2^2 \cdot 6 = 4 \cdot 6 = 24mW$$

All answers = 24 milli-watts (24mW)

Q-34 Calculate the Total Power ($P_t$) in the following circuits.







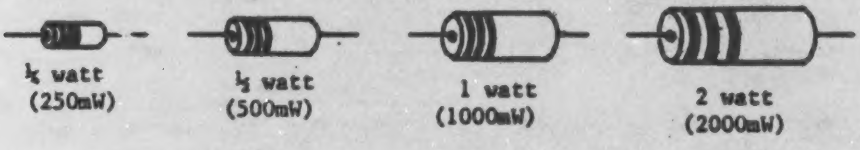
A-33

a. $P_t = 120mW\ (.12W)$ b. $P_t = 192mW\ (.192W)$

## POWER DISSIPATION vs POWER RATING

A resistor, in an operating circuit, will produce heat. This is called its POWER DISSIPATION. However, there is a limit to the amount of heat a particular resistor can withstand, without damage. This "limit" is called its POWER RATING.

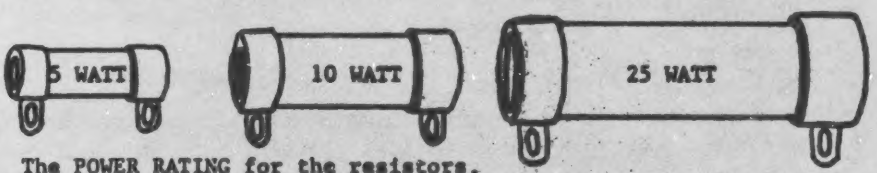
The POWER RATING of a resistor is determined by its physical size (surface area). Carbon resistors are typically "rated at".......



Suppose the power calculation for a resistor came-out-to-be 1200mW. The smallest POWER RATING that could be used, would be the 2 watt (2000mW) size. Anything smaller would "burn-up".

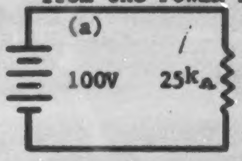
If the power calculation came-out to be 300mW, the minimum POWER RATING that could be used, would be the ½ watt (500mW) size.

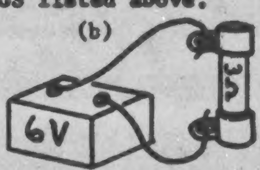
Above 2 watts (2000mW), wire-wound resistors are employed. They are capable of withstanding greater amounts of heat.

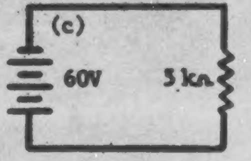


The POWER RATING for the resistors, will be shown in the "parts list" accompanying the equipment.

Q-35 Determine the minimum POWER RATING for these resistors. Choose from the POWER RATINGS listed above.







A-34

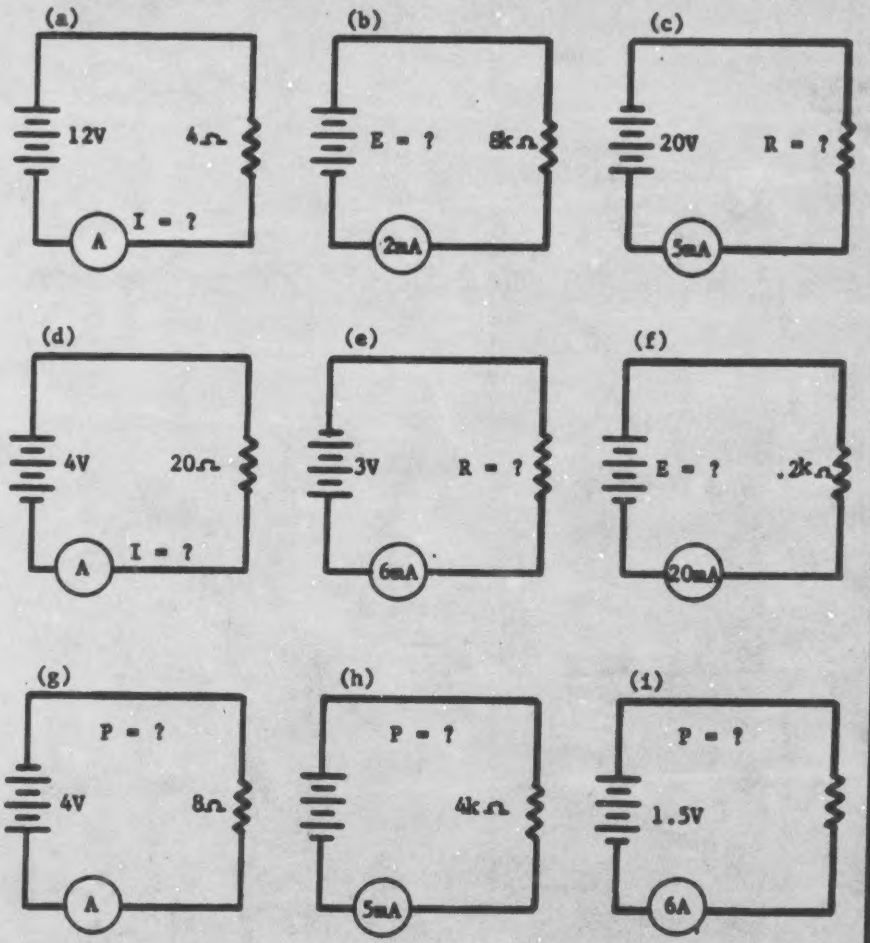
a. 40W b. 300W c. 4mW (.004W)

PRACTICE PROBLEMS

Test your skills in Series Circuits with the problems which follow. The first step is to make sure of the "question". Then form a "plan of attack" toward the solution.

This series of problems will start "simple", and progress to the more "difficult" types. A list of the three Ohm's Law equations, and the various power equations may make the work faster, and more accurate.

Q-36 Solve as indicated.

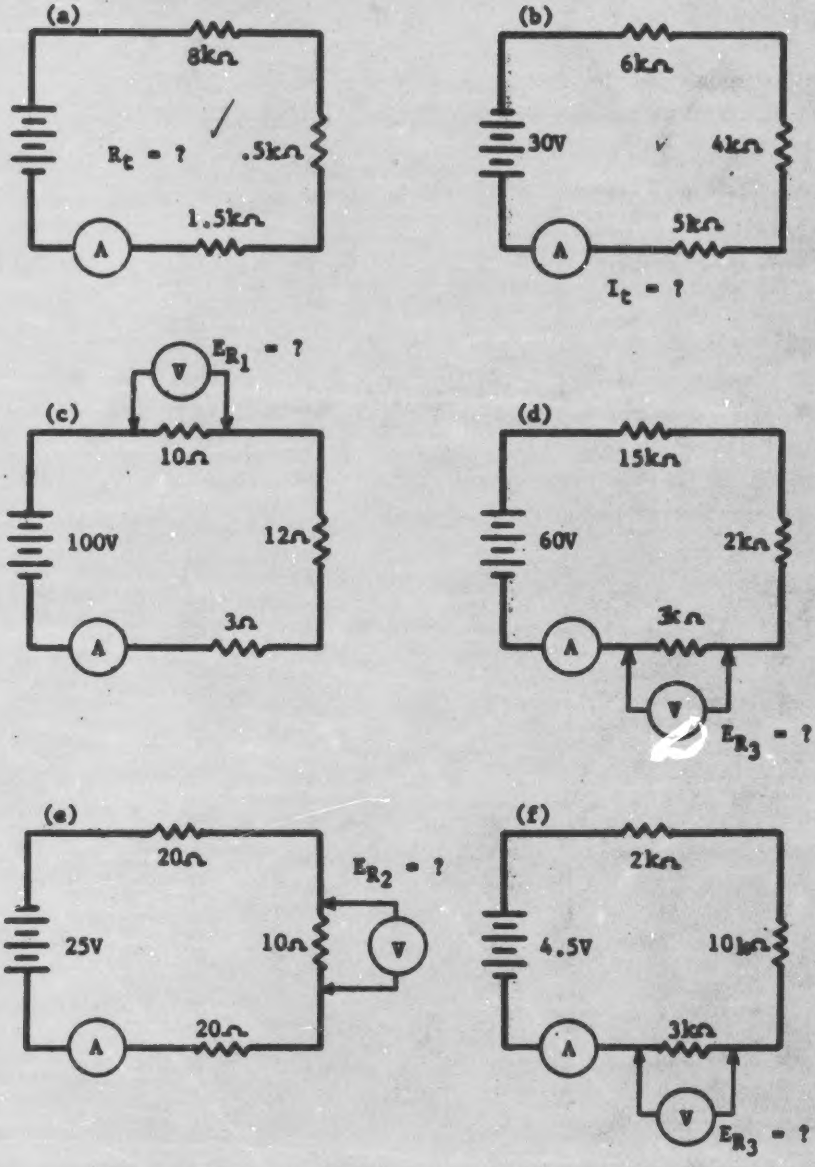


A-35 **POWER DISSIPATION...... a. 400mW .... b. 12W ..... c. 720mW**

**MINIMUM POWER RATING....... ½W ......... 25W ........ 1W**

PRACTICE PROBLEMS (cont)

Q-37 Solve as indicated.



A-36

a. 3A
b. 16V
c. 4kΩ

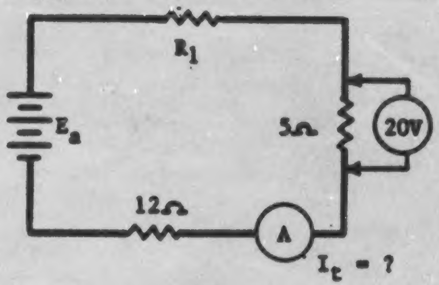
d. .2A
e. .5kΩ
f. 4V

g. 2W
h. 100mW
i. 9W

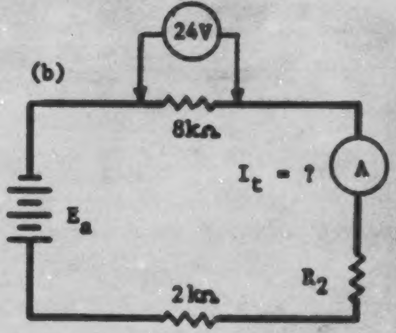
PRACTICE PROBLEMS (cont)

Q-38 Solve as indicated.

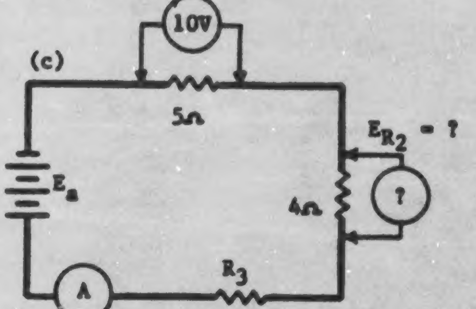
(a)



(b)



(c)



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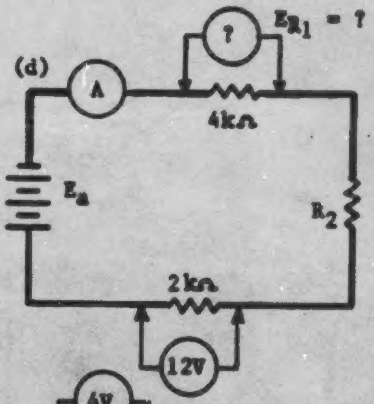

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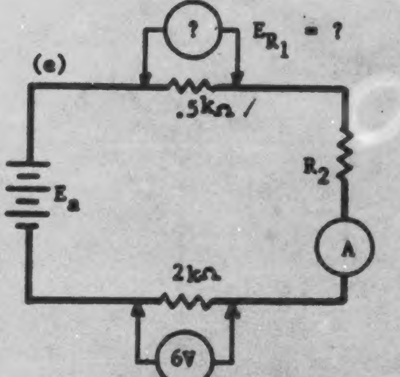

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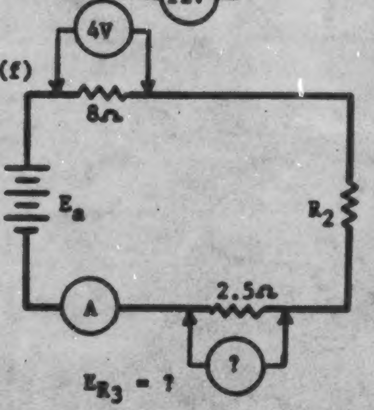


611

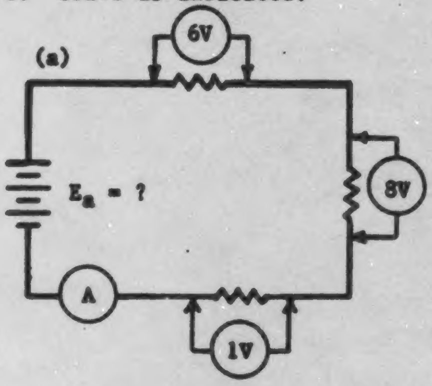
A-37

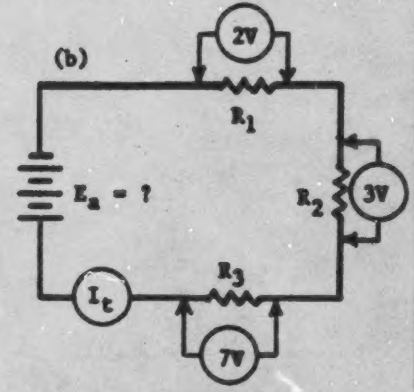
a. 10KΩ  c. 40V  e. 5V

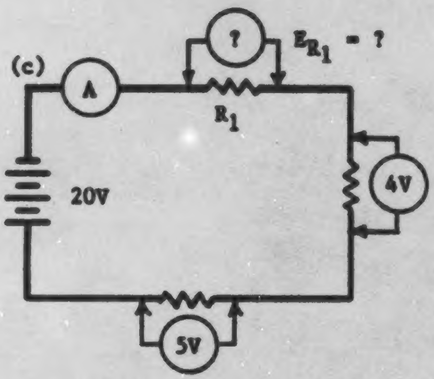
b. 2mA  d. 9V  f. .9V

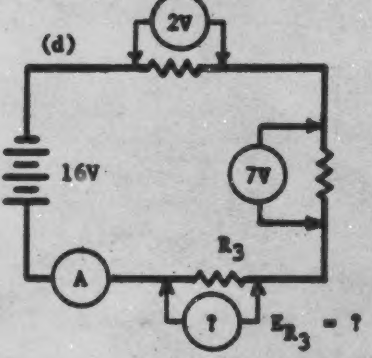
PRACTICE PROBLEMS (cont)

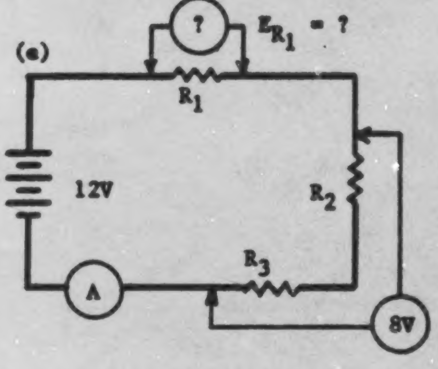
Q-39 Solve as indicated.

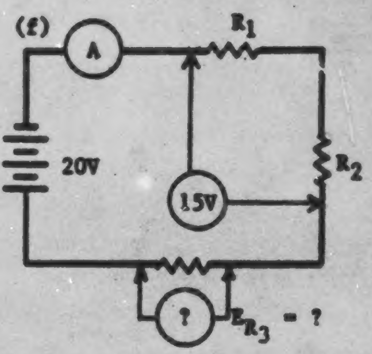








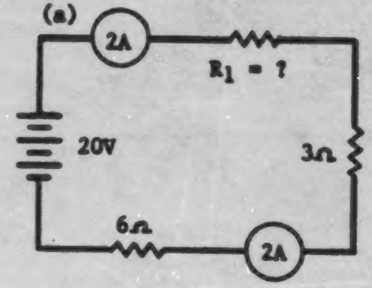


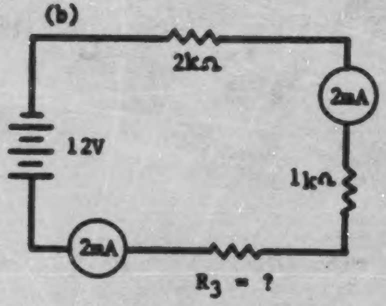


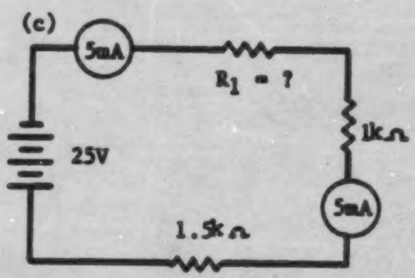
A-38
a. 4A
b. 3mA
c. 8V
d. 24V
e. 1.5V
f. 1.25V

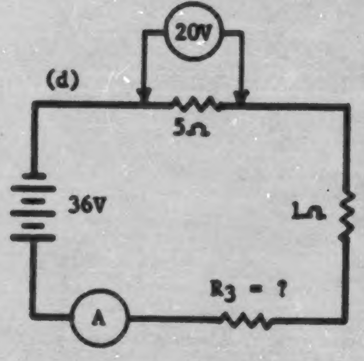
PRACTICE PROBLEMS (cont)

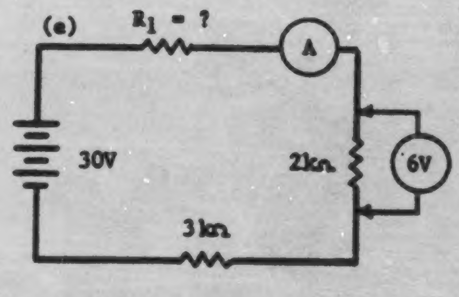
Q-40 Solve as indicated.

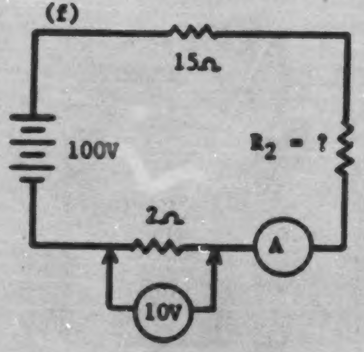












A-39

a. 15V

b. 12V

c. 11V

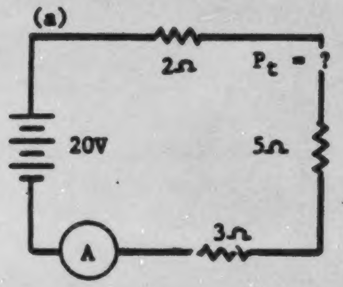
d. 7V

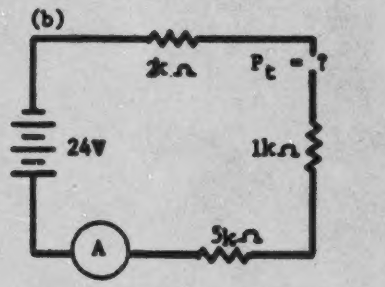
e. 4V

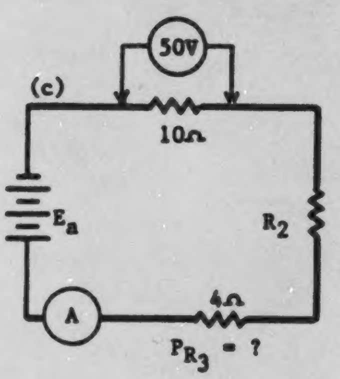
f. 5V

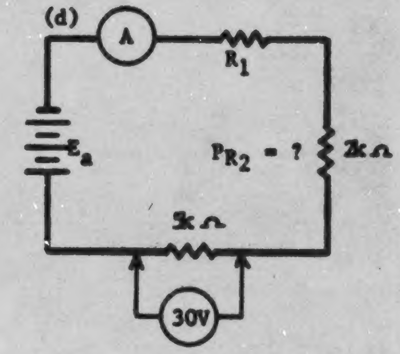
**PRACTICE PROBLEMS** (cont)

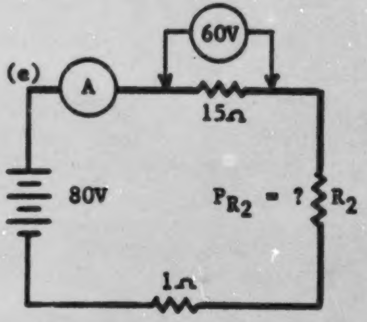
Q-41 Solve as indicated.

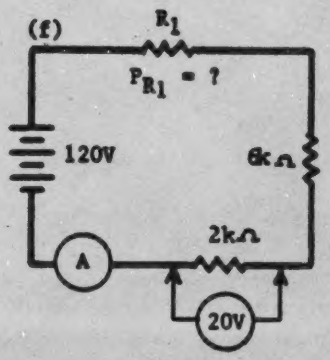












A-40

a. 1Ω

b. 3kΩ

c. 2.5kΩ

d. 3Ω

e. 5kΩ

f. 3Ω

SUMMARY

The study of Series Resistive Circuits should NOT end here. More advanced theory involving these circuits is available in texts obtained at Technical Study Centers. Use of these technical publications will broaden your understanding in this subject area.

This text has reviewed the basic relationships between: Voltage, Current, and Resistance. The concepts of "voltage drops", and Electrical Power have been introduced.

The calculations involved in these Series Circuits, are fundamental to all Electronic circuits. The use of Ohm's and Kirchoff's Laws will continue in every area of the Electronics Career Field.

Series Circuits are used in every type of Electronic equipment. They supply many of the needed "operating voltages" for transistors, integrated circuits, and tubes. Your ability to locate troubles in this type of circuit, depends largely upon your understanding of the expected results and performance of Series connected components.

**The Series Resistive Circuit**...............the "Foundation".

A-41

a. 40W

b. 72mW

c. 100W

d. 72mW

e. 64W

f. 400mW

**NOTES**

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Prepared by Keesler TTC
KEP-GP-7

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED

## MODULE 7

## SERIES RESISTIVE CIRCUITS

1 June 1974

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# ELECTRONIC PRINCIPLES

## MODULE 7

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

| TITLE | PAGE |
|---|---|
| Overview | 1 |
| List of Resources | 2 |
| Digest | 3 |
| Adjunct Guide | 5 |
| Module Self Check | 13 |

Supersedes KEP-GP-7, 1 November 1973. Use existing stock until exhausted.

# SERIES RESISTIVE CIRCUIT

1. SCOPE: The basic circuit in electronics is the series circuit. Even complex circuits are interconnected series circuits. This module discusses the requirements of a DC circuit and the application of Ohm's law. You will solve DC series resistive circuit problems for resistance, current, and power.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

   a. Given four diagrams, select the one which satisfies the requirements for a DC circuit.

   b. From a group of statements, select the one that describes Ohm's law as related to current, voltage, and resistance.

   c. Given a series circuit schematic diagram and formulas, solve for:

      (1) total resistance.

      (2) total current.

      (3) total power.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

## SERIES RESISTIVE CIRCUIT

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

AUDIO VISUALS:

Television Lesson, Series Resistive Circuits, TVK 30-101L

Television Lesson, Power, TVK 30-101M

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

## SERIES RESISTIVE CIRCUITS

### CIRCUIT REQUIREMENTS

In order to have a practical DC circuit, certain conditions must exist. There must be a power source, a load device, and a conductor. All of these components must be connected in a manner to provide a complete path for current flow from the negative terminal of the source to the positive terminal of the source.

### OHM'S LAW

In any circuit, current (I), voltage (E), and resistance (R) conforms to OHM'S LAW which states that, current in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance.

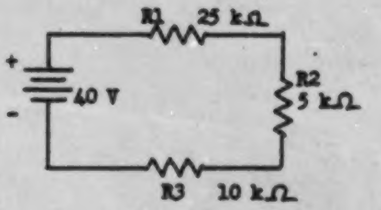
Or: $I = \frac{E}{R}$

Therefore: $R = \frac{E}{I}$

And: $E = IR$

### SERIES CIRCUIT ANALYSIS

In a series circuit, all components are connected end-to-end and there is only one path for current flow. Study the circuit shown.



In a series circuit, total resistance is found by adding the individual resistances.

Or: $R_t = R1 + R2 + R3 + \ldots\ldots$

Then: $R_t = 25\ k\Omega + 5\ k\Omega + 10\ k\Omega$

$R_t = 40\ k\Omega$

To find current, use Ohm's Law.

Or: $I = \frac{E_a}{R_t}$

Then: $I = \frac{40\ V}{40\ k\Omega}$

$I = 1 \times 10^{-3}$ A or 1 mA

## DIGEST

When current flows through a load device, heat is produced and electrical power is consumed or dissipated. The power dissipated (P) is measured in watts (W) and is calculated from the following formulas:

$$P = I^2R$$

$$P = \frac{E^2}{R}$$

$$P = IE$$

Find the power dissipated in figure 1.

$$P = I^2R$$

$$P = (1 \times 10^{-3})^2 \times (40 \times 10^3)$$

$$P = (1 \times 10^{-6}) \times 40 \times 10^3$$

$$P = 40 \times 10^{-3} \text{ W or } .04 \text{ W}$$

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## SERIES RESISTIVE CIRCUITS

**INSTRUCTIONS:**

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to Student Text Volume I and read paragraphs 5-1 thru 5-10. Return to this page and answer the following questions.

1. What are the three basic requirements for any circuit?

   ____________ ____________ ____________

2. In the external circuit, current flow is always from ________ to ________.
3. The formula for total resistance in a series circuit is ____________.
4. The formula for Ohm's Law is ____________.
5. Ohm's Law states that ____________

   ____________

   ____________.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

B. Turn to Student Text Volume I and read paragraphs 5-11 thru 5-24. Return to this page and answer the following questions.

1. The sum of the voltage drops in a series circuit are equal to the ____________.
2. In a series circuit containing R1 and R2, if $E_{R1}$ equals 10 volts and $E_{R2}$ equals 30 volts, then $E_2$ equals ________.
3. To find "R", what must be known? ____________.
4. To find "E", what must be known? ____________.
5. To find "I", what must be known? ____________.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

ADJUNCT GUIDE

**ANSWERS TO A:**

1. source of power, load device, conductor.
2. negative to positive.
3. $R_t = R1 + R2 + R3 + \text{etc.}$
4. $I = \frac{E}{R}$
5. The current in a circuit is directly proportional to the applied voltage and inversely proportional to its resistance.

If you missed ANY questions, review the material before you continue.

**ANSWERS TO B:**

1. Applied voltage
2. 40 volts
3. E & I
4. I & R
5. E & R

If you missed ANY questions, review the material before you continue.

C. Turn to Student Text Volume I and read paragraphs 5-25 thru 5-39. Return to this page and answer the following questions.

1. Kirchhoff's Law for current states that ____________________________________

    ____________________________________________________________

    ____________________________________________________________.

2. Kirchhoff's Law for voltage states that ______________________________

    ____________________________________________________________

    ____________________________________________________________.

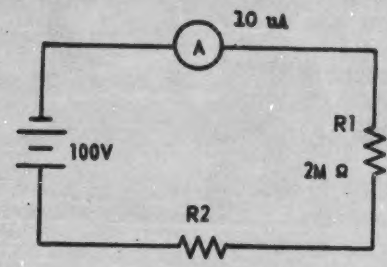
3. What is the resistance of R2?

_____a. 50 megohms

_____b. 10 megohms

_____c. 8 megohms

_____d. 5 megohms



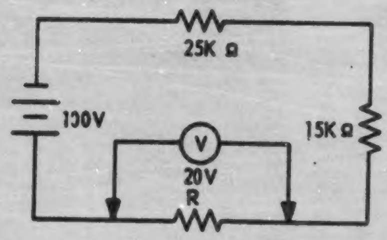
4. What is the resistance of R?

_____a. 5 k ohms

_____b. 10 k ohms

_____c. 20 k ohms

_____d. None of the above



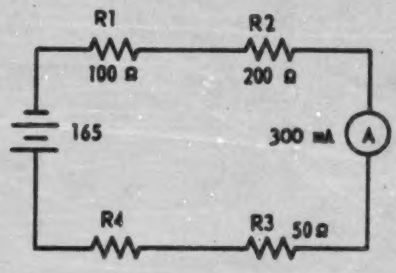
5. What is the value of R4?

_____a. 400 ohms

_____b. 200 ohms

_____c. 50 ohms

_____d. 40 ohms



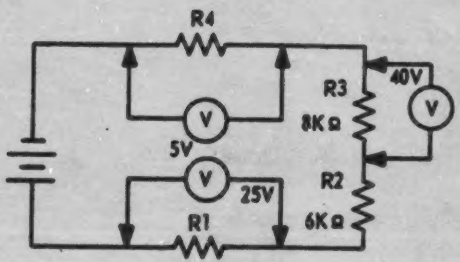
6. What is the value of R1?

_____a. 10 k ohms

_____b. 15 k ohms

_____c. 5 k ohms

_____d. 20 k ohms



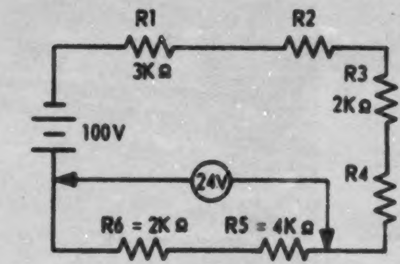
7. What is the total resistance?

_____a. 13 k ohms

_____b. 25 k ohms

_____c. 192 k ohms

_____d. 8 k ohms



## ADJUNCT GUIDE

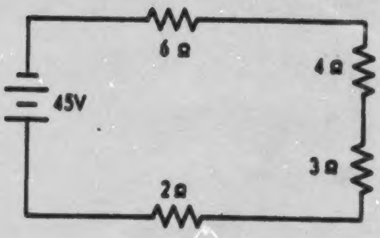
8. What is the total current?

____a. 9.0 amps

____b. 7.5 amps

____c. 3 amps

____d. 3 milliamps



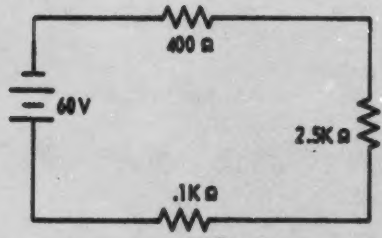
9. The current is:

____a. 0.91A.

____b. 91 mA.

____c. 0.2A.

____d. 20 mA.



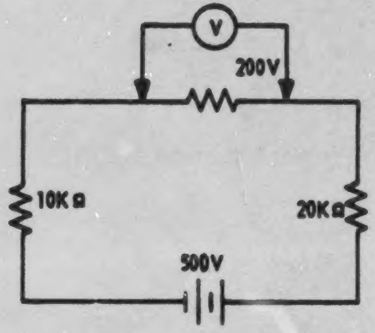
10. The current is:

____a. 5 mA.

____b. 50 mA.

____c. 25 mA.

____d. 10 mA.



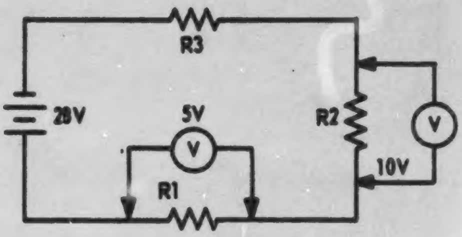
11. If the current is 10 mA, R3 is:

____a. 1.3 k ohms.

____b. 2 k ohms.

____c. 1 k ohms.

____d. .5 k ohms.



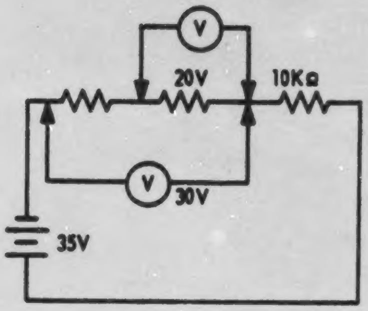
12. The current is:

____a. .2 mA.

____b. 15 mA.

____c. 10 mA.

____d. .5 mA.



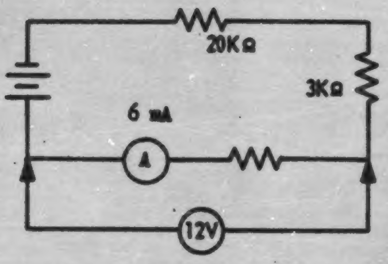
13. What is the applied voltage?

_____a. 138 V

_____b. 72 V

_____c. 150 V

_____d. 210 V



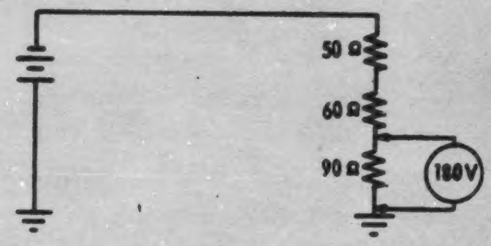
14. The voltage applied is:

_____a. 2 millivolts

_____b. 400 volts

_____c. 400 amps

_____d. 200 volts



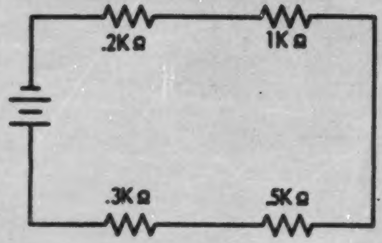
15. If I is 25 mA, $E_a$ is:

_____a. 50 V.

_____b. 12.5 V.

_____c. 25 V.

_____d. 100 V.



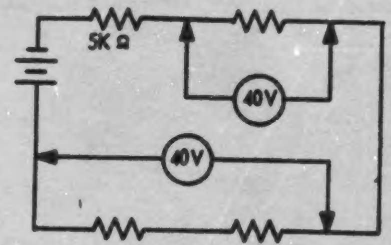
16. If I is 2 mA, the value of $E_a$ is:

_____a. 20 V.

_____b. 90 V.

_____c. 40 V.

_____d. 60 V.



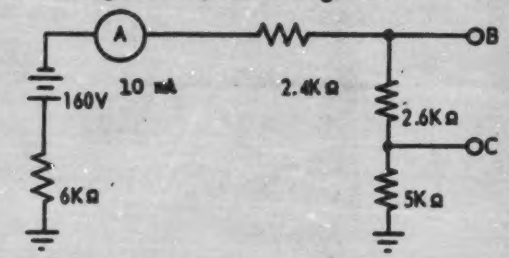
17. From the given information, determine the voltage from point B to ground.

_____a. -.76 volts

_____b. -7.6 volts

_____c. -76 volts

_____d. -160 volts



ADJUNCT GUIDE

D. Turn to Student Text Volume I and read paragraphs 5-40 thru 5-60. Return to this page and answer the following questions.

1. Energy is defined as ______________________________

______________________________________

2. Power is defined as ______________________________

______________________________________.

3. When I and R are known, the formula for power is ______________________.

4. When E and R are known, which power formula is used? ______________.

5. When E and I are known, which power formula is used? ______________

6. The unit of measurement for electrical power is the ______________.

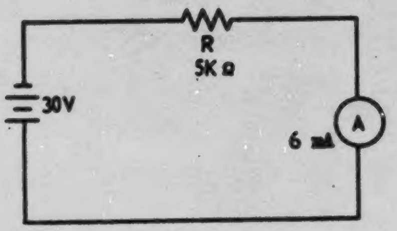
7. The lowest power rating for R is:

_____a. 2 W.

_____b. 1 W.

_____c. 100 mW.

_____d. 200 mW.



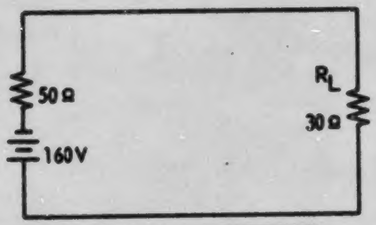
8. The power dissipated by $R_L$ is:

_____a. 160 watts.

_____b. 60 watts.

_____c. 120 watts.

_____d. 30 watts.



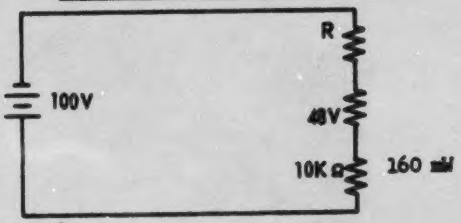
9. What is the power dissipated by R1?

_____a. 480 mW

_____b. 192 mW

_____c. 48 mW

_____d. 48 W



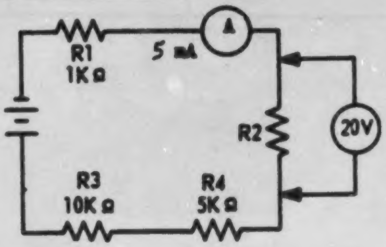
10. What should be the minimum power rating of R3?

_____a. .52 W

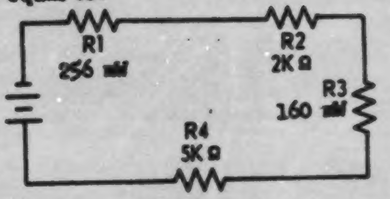
_____b. 2.5 W

_____c. .25 W

_____d. 50 mW



11. If R4 dissipates half the power of R3, $P_t$ is equal to:



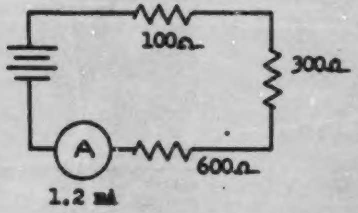
_____ a. 1008 mW.

_____ b. 800 mW.

_____ c. 528 mW.

_____ d. 504 mW.

12. Find total power.



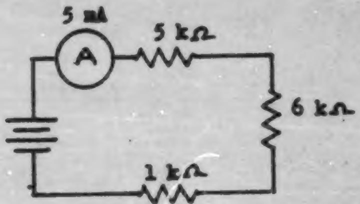
_____ a. 1.2 mW

_____ b. 1.44 mW

_____ c. 1.2 W

_____ d. 1.44 W

13. Find $E_a$.



_____ a. 50 V

_____ b. 60 V

_____ c. 500 V

_____ d. 600 V

14. Find total power for the circuit in question 13.

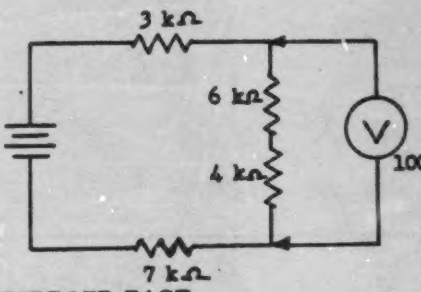
_____ a. 100 mW

_____ b. 200 mW

_____ c. 300 mW

_____ d. 400 mW

15. Find total power.



_____ a. 2W

_____ b. 1W

_____ c. 20 mW

_____ d. 10 mW

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ANSWERS TO C:

1. The sum of all currents flowing to a point must be equal to the sum of all the currents flowing away from that point.

2. The applied voltage is equal to the sum of the voltage drops around the circuit.

3. c
4. b
5. b
6. c
7. b
8. c
9. d
10. d
11. a
12. d
13. c
14. b
15. a
16. b
17. c

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. The capacity to do work.

2. The time rate of developing or expending energy.

3. $P = I^2R$

4. $P = \frac{E^2}{R}$

5. $P = IE$

6. Watt

7. d

8. c

9. c

10. c

11. c

12. b

13. b

14. c

15. a

If you missed any questions review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## SERIES RESISTIVE CIRCUITS

**QUESTIONS:**

1. What are the three basic requirements for any circuit?

_______________ _______________ _______________

2. In the external circuit, current flow is always from ________ to ________ .

3. The formula for total resistance in a series circuit is ________________ .

4. The formula for Ohm's Law is ________________ .

5. Ohm's Law states that ________________________________

________________________________________________

________________________________________________ .

6. Energy is defined as ________________________________

________________________________________________ .

7. Power is defined as ________________________________

________________________________________________ .

8. The unit of measurement for electrical power is the ________________ .

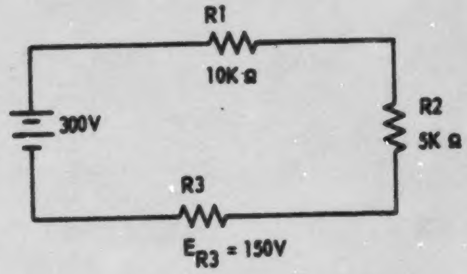
9. In the circuit shown

   a. total resistance is ____________ .

   b. total current is ____________ .

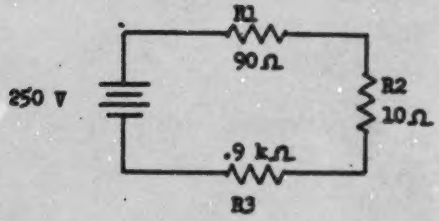
   c. total power is ____________ .

   Remember, $E = IR$ and $P = IE$



SELF-CHECK

10. Total current is:



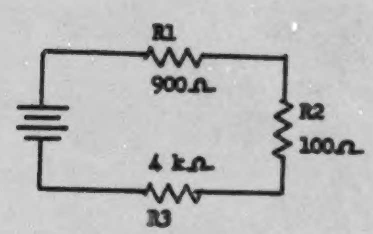
_______a. 25 mA.

_______b. 250 mA.

_______c. 1 A.

_______d. 25 A.

11. Find total resistance:



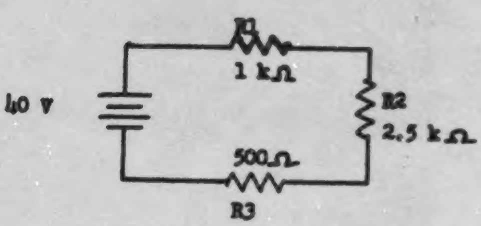
_______a. 1004 Ω

_______b. 4 k Ω

_______c. 5 k Ω

_______d. 6 k Ω

12. Find total power:



_______a. 400 W.

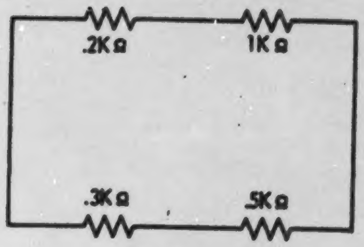
_______b. 400 mW

_______c. 500 mW

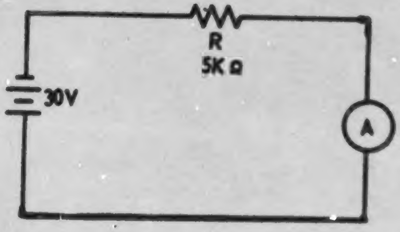
_______d. 1 W

13. Select the diagram that satisfies the requirements for a DC circuit.

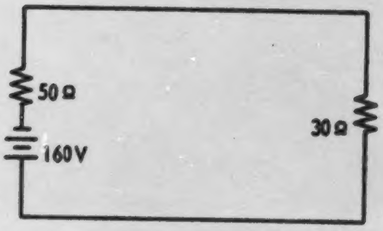
A.



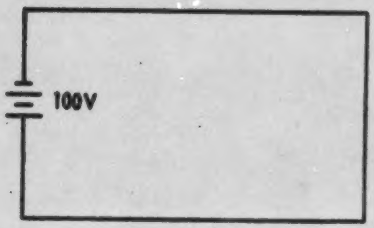
B.



C.



D.



CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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SELF-CHECK

**ANSWERS:**

1. source of power, load device, conductor.
2. negative to positive.
3. $R_t = R1 + R2 + R3 + \text{etc.}$
4. $I = \frac{E}{R}$
5. The current in a circuit is directly proportional to the applied voltage and inversely proportional to its resistance.
6. The capacity to do work.
7. The time rate of developing or expending energy.
8. Watt
9. a. 30 k $\Omega$

   b. 10 mA

   c. 3 W
10. b
11. c
12. b
13. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

ATC PT 3AQR30020-1
Prepared by Keesler TTC
KEP-PT-8

Technical Training

# Electronic Principles (Modular Self-Paced)

## Module 8

# PARALLEL RESISTIVE CIRCUITS
# (Including Bridge Circuits)

November 1975

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

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ATC Keesler 6-2378

Radar Principles Branch
Keesler Air Force Base, Mississippi

Programmed Text 3AQR3X020-X
KEP-PT-8
November 1975

# Electronic Principles
## Module 8

This illustrated Programmed Text is designed to aid in the study of Parallel Resistive Circuits and Bridge Circuits. Each page contains an important idea or concept to be understood, before proceeding to the next. An illustration for each objective is presented to clarify what is to be learned.

At the bottom of each page, there are a few questions to bring out the main points. These are indicated as... It is hoped that these questions also aid understanding the subject a little better.

Q-1, Q-2, etc.

The answers to these questions will be found on the top of a following page, indicated as.... Short comments may follow the answers to help understand why a question may have been missed.

A-1, A-2 etc.

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### OBJECTIVES

Upon completion of this module, you should be able to satisfy the following objectives:

a. From a group of statements select the ones that describe Kirchoff's Laws for current and voltage.

b. Given a parallel circuit schematic diagram and formulas, solve for:

(1) total resistance.

(2) total current.

(3) total power.

c. Given a bridge circuit schematic diagram, make necessary calculations to determine whether the circuit is balanced or unbalanced.

Supersedes KEP-PT-8, 1 November 1974
Previous editions may be used.

## INTRODUCTION

One day my boss said, "Hook-up those resistors in parallel with that battery." Following his instructions, the circuit was constructed. Then he asked, "Now....what have you got?". After a short while, I was able to give him the only correct answer....... "A dead battery!!!".

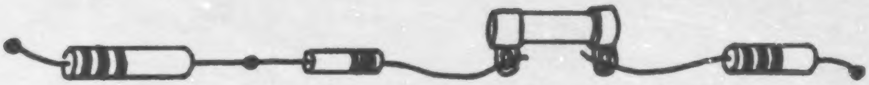
There is no real use for resistors connected in Parallel with a power source. There ARE however, basic and important principles to be learned from such an arrangement. The principles of "Parallel Operation".

It is essential that Electronic circuits within Transmitters, Receivers, and Control Systems, be powered from one "source". This is the basic element of parallel circuit construction, and the reason for its study. With few exceptions, all electrical power systems are Parallel Circuits. Homes, offices, factories, and Electronic equipment are all wired in Parallel.

This then, is NOT a study of resistors connected in Parallel, but of [what happens?] when electrical components of all types are connected in this manner.

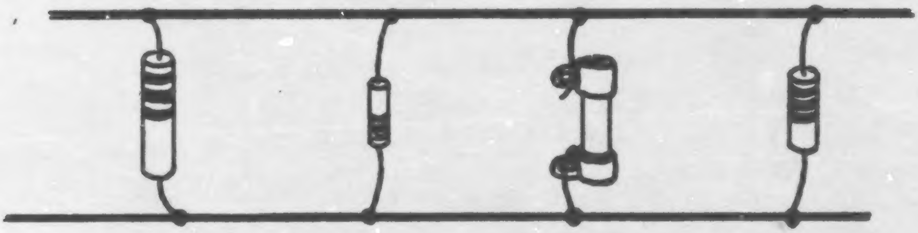
## RESISTORS CONNECTED IN SERIES

The "series" circuit consists of resistors connected end-to-end.



## REISITORS CONNECTED IN PARALLEL

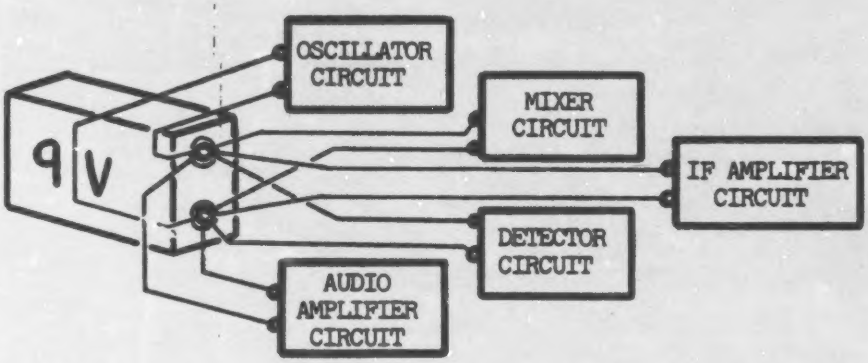
A "parallel" circuit consists of the same resistors, connected side-by-side. Components other than resistors can be used.



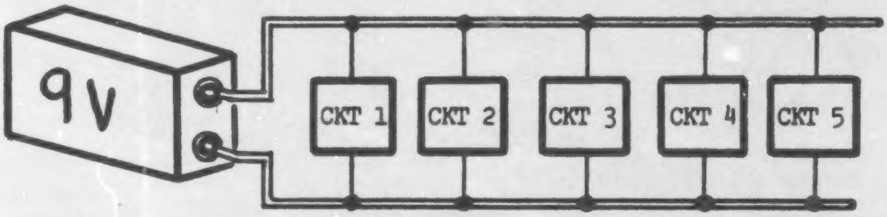
Q-1 a. Series circuits consist of resistors connected ____ __ ____.
b. Parallel circuits consist of resistors connected ______ __ ______.
c. Homes, offices, factories, and Electronic equipment are all wired in ______________.
d. T-F Most of the time, resistors are connected in parallel with a battery.

## USE OF PARALLEL CIRCUITS

A small transistor radio may consist of 5 or more separate electronic circuits. Each of these circuits requires a source of power in order to operate. It would be impractical to have 5 or more separate batteries as power sources. Instead, each circuit is designed to operate properly [at say....9 volts], and then all the circuits are attached to one, 9 volt battery.



By extending the battery leads, this parallel arrangement can be simplified as follows.



In this manner, each circuit receives its "operating voltage" from the 9 volt power source (battery).

Q-2
a. With a parallel connection, each circuit receives its power from ________ power source.
b. T-F In parallel wiring, each circuit is powered by the same ____________.
c. The same voltage is applied to each circuit in a ________ connection.
d. T-F With a parallel connection, each circuit receives a different "operating voltage".

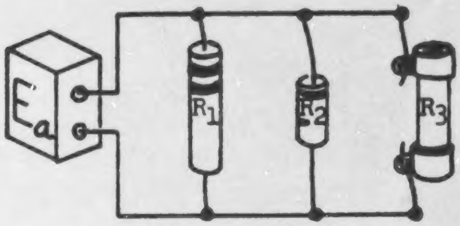
A-1
a. end-to-end.
b. side-by-side.
c. parallel.
d. False....unless you want to wear-out the battery.

## THE BASIC PARALLEL CIRCUIT

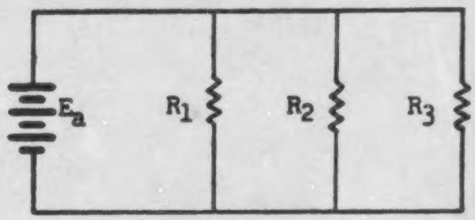
Instead of connecting entire electronic "circuits" in parallel with a power source, resistors will be used. The principles of "parallel" operation remain the same. Using resistors simplifies the understanding, and makes calculations easier.

However, there are times when resistors are actually connected in parallel with each other. The reasons for this will be explained later in the text.

THE BASIC PARALLEL CIRCUIT



PICTORIAL DIAGRAM



SCHEMATIC DIAGRAM

The source of power [the battery] is referred to as the Applied Voltage (Symbol $E_a$). The resistors are usually numbered $R_1$, $R_2$, $R_3$, beginning nearest the battery.

3 Branches

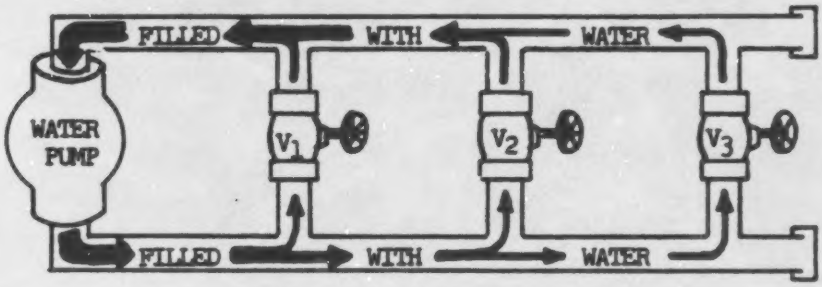
Each "leg" of the parallel circuit is called a BRANCH. For example: The above circuit has an $R_1$ branch, an $R_2$ branch, and an $R_3$ branch. Each "branch" is connected to the power source, therefore each branch has the Applied Voltage ($E_a$) as a voltage source.

Q-3
a. Each "leg" of a parallel circuit is called a __________.
b. T-F Each branch of a parallel circuit has the Applied Voltage ($E_a$) as its power source.
c. T-F Only one branch can be connected to a power source.
d. In a parallel connection, each branch receives power from the same __________________.

A-2
a. the same....a common....or words to that effect.
b. battery....voltage....power source....that's the main reason for the parallel connection.
c. parallel
d. False....each circuit receives the same "operating voltage".

## HYDRAULIC ANALOGY

Each parallel branch will have electrons flowing thru it. The amount of current allowed to flow thru each branch depends upon the opposition of the resistor in that branch. The "hydraulic analogy" may help to clarify this point.



The water allowed to flow thru each "branch", depends upon the setting of the valve in that branch. Of course, the pump pressure also plays a part. Increasing the pump pressure will force more water to flow thru all the branches.

*Important*

Now, a VERY important point!!!!

Changing the setting of any ONE valve, affects the water flowing thru that ONE branch ONLY!! It has NO EFFECT on the water flowing thru the other branches!! There is not a CERTAIN amount of water which must come-out of the pump. There is a VARYING amount of water "allowed" to flow out of the pump, depending on the settings of all the valves. [Read again]

Q-4 a. The amount of current allowed to flow thru a branch, depends upon the __________ of the resistor in that branch.
b. T-F Changing the opposition in one branch has NO EFFECT on the current flow thru the other branches.

A-3
- a. branch.
- b. True....that's the main reason for parallel connections.
- c. False...any number of branches can be connected.
- d. voltage.....power source....or similar words.

## CALCULATING BRANCH CURRENTS

It is important, in parallel circuits, to know the amount of current flowing thru each branch. To see how these currents are calculated, review for a moment.......

(1) "Each branch is connected to the power source, therefore each branch has the Applied Voltage as a voltage source."

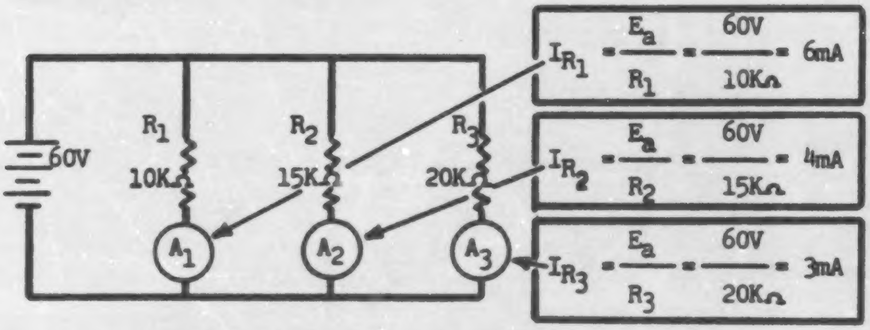
(2) "The amount of current allowed to flow thru each branch, depends upon the opposition of the resistor in that branch."

Ohm's Law then, can be used to calculate the branch currents.

*Equation* $\boxed{I = \frac{E}{R}}$

$$\boxed{I_{\text{[each branch]}} = \frac{\text{Applied Voltage}}{R_{\text{[each branch]}}}}$$

EXAMPLE: Determine the current flow thru each branch.



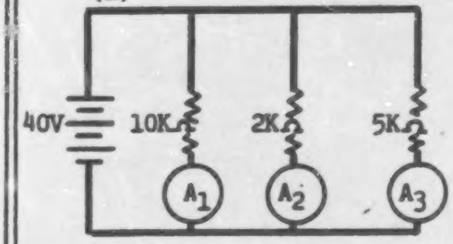
$$I_{R_1} = \frac{E_a}{R_1} = \frac{60V}{10K\Omega} = 6mA$$

$$I_{R_2} = \frac{E_a}{R_2} = \frac{60V}{15K\Omega} = 4mA$$

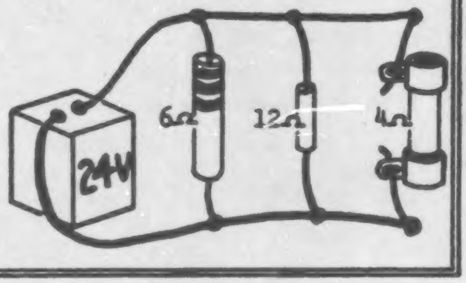
$$I_{R_3} = \frac{E_a}{R_3} = \frac{60V}{20K\Omega} = 3mA$$

Q-5 Calculate the current flow thru each branch.

(a)



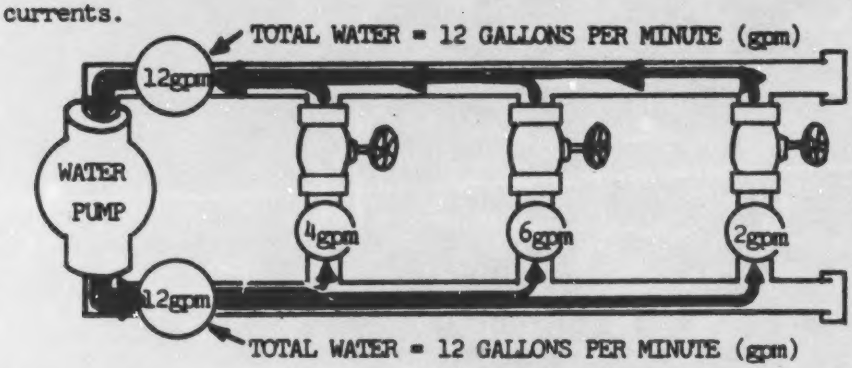
(b)



A-4 a. opposition or resistance.....increasing the opposition, decreases the flow of current thru that branch.
b. True....each branch is "independent" of the other branches, but they all are connected to the same battery.

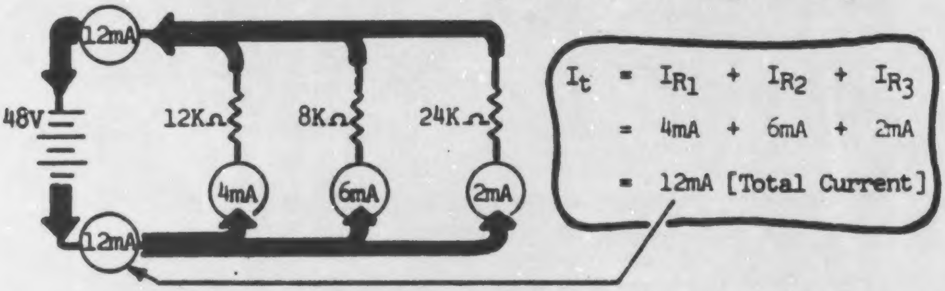
DETERMINING TOTAL CURRENT

The "hydraulic analogy" shows the total water, allowed to flow out-of and back-into the pump, is the SUM of the individual branch currents.


TOTAL WATER = 12 GALLONS PER MINUTE (gpm)
12gpm
WATER PUMP
4gpm
6gpm
2gpm
12gpm
TOTAL WATER = 12 GALLONS PER MINUTE (gpm)

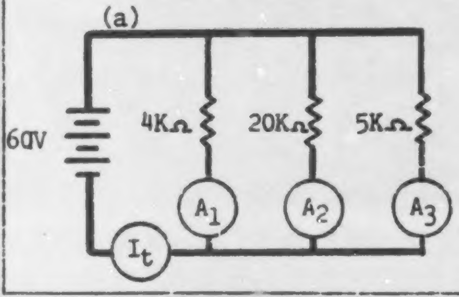
In an electric circuit, the Total Current ($I_t$) is the amount flowing out-of, and back-into the battery. It is the SUM of the individual branch currents.

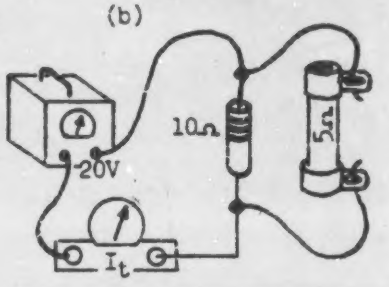
$$I_t = I_{R_1} + I_{R_2} + I_{R_3}$$



$$\begin{aligned} I_t &= I_{R1} + I_{R2} + I_{R3} \\ &= 4\text{mA} + 6\text{mA} + 2\text{mA} \\ &= 12\text{mA [Total Current]} \end{aligned}$$

Q-6 Determine the Total Current ($I_t$) in the following circuits.

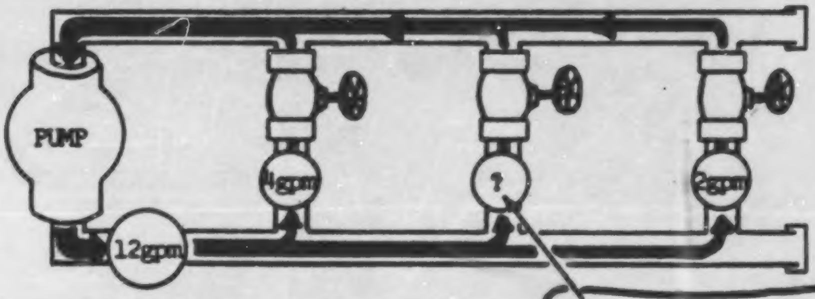




A-5 a. Branch 1 = 4mA Branch 2 = 20mA Branch 3 = 8mA
b. Branch 1 = 4A Branch 2 = 2A Branch 3 = 6A

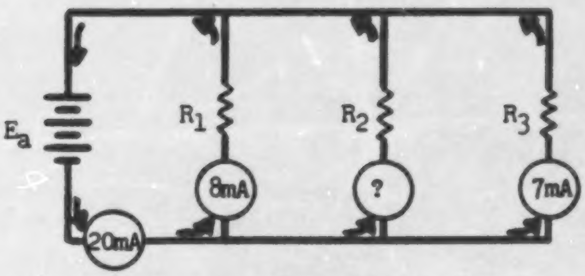
## MISSING BRANCH CURRENT ?

Suppose the Total Current ($I_t$) is given, and one of the branch currents is NOT. Subtraction can be used to determine the missing branch current. Observe the "hydraulic analogy" for a moment......



A little ADDITION and SUBTRACTION = Must be the other 6gpm

In an electric circuit, a missing branch current is determined the same way. A little addition and subtraction = missing current!

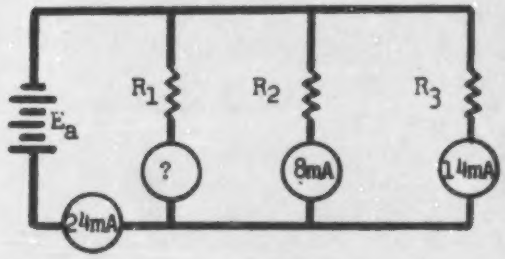


$$I_{R_1} + I_{R_3} = 15mA$$

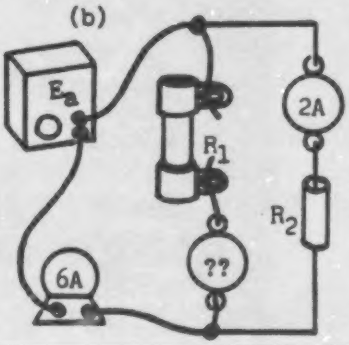
$$\begin{aligned} I_{R_2} &= I_t - 15mA \\ &= 20mA - 15mA \\ &= 5mA \end{aligned}$$

Q-7 Determine the "missing current" in the following circuits.

(a)



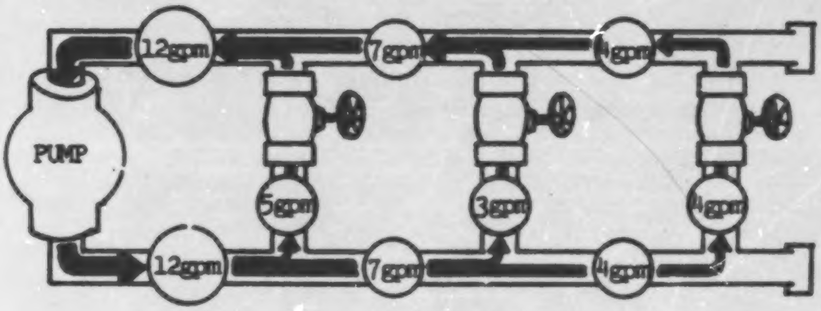
(b)



A-6 a. $I_t = 30mA$ b. $I_t = 6A$

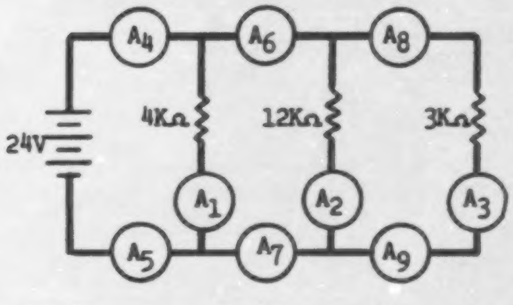
## PARALLEL CURRENT MEASUREMENTS

Electrical current can be measured at many different points in a parallel circuit. The readings will vary. It depends upon the point at which the ammeter measurement is made. The "hydraulic analogy" may help to clarify these different current readings.



Ammeter readings vary, depending upon the point of measurement.

EXAMPLE: In the following circuit, determine all ammeter readings.



Using Ohm's Law....

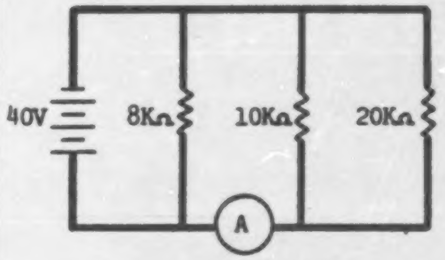
$$\left.\begin{array}{l} A_1 = 6mA \\ A_2 = 2mA \\ A_3 = 8mA \end{array}\right\} A_4 \text{ and } A_5 = I_t = 16mA$$

$$A_6 \text{ and } A_7 = A_2 + A_3 = 10mA$$

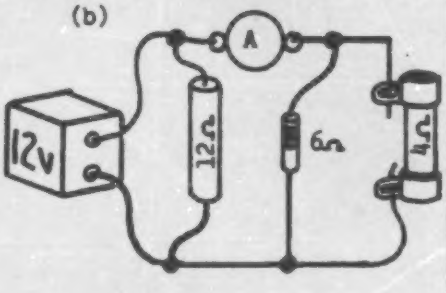
$$A_8 \text{ and } A_9 = A_3 = 8mA$$

Q-8 Determine the ammeter reading in the following circuits.

(a)



(b)



| A-7 | a. 2mA | b. 4A |
|---|---|---|

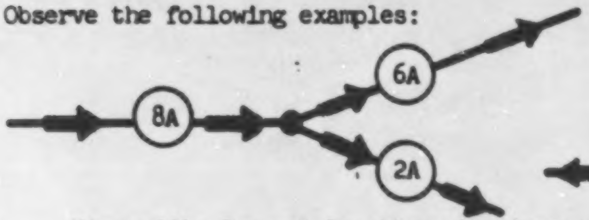
## KIRCHOFF'S CURRENT LAW

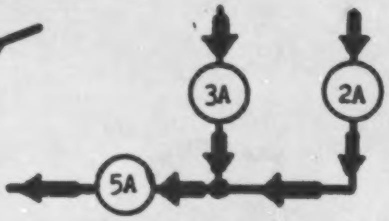
Throughout the study of parallel circuits, Kirchoff's Current Law has been used. It states (in effect).....

**KIRCHOFF'S CURRENT LAW**

> The current flowing toward a point, is equal to the current flowing away from that point.

Observe the following examples:

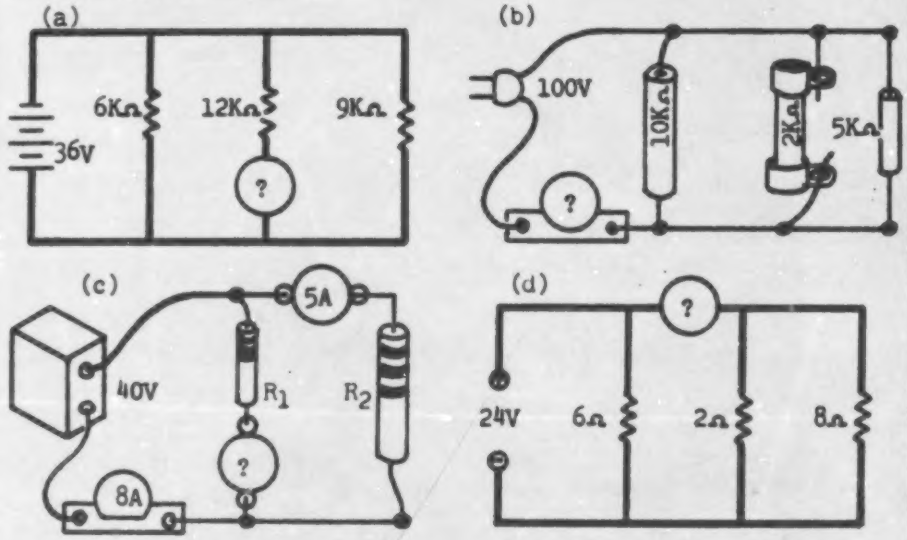




Kirchoff's Current Law then, has been used when adding "branch" currents to obtain the Total Current ($I_t$). "Missing" branch currents were also determined using this law. Watch for the use of Kirchoff's Current Law in the solution of electronic circuits later on.

## PRACTICE PROBLEMS

Q-9 Solve as indicated.



| A-8 | a. 6mA | b. 5A |
|---|---|---|

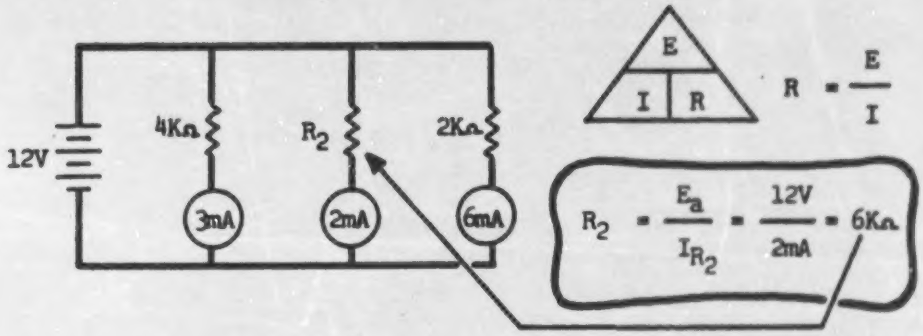
## CALCULATING BRANCH RESISTANCE

The electron flow thru a parallel branch, is controlled by the resistance (ohms) of that branch. Occasionally, it is necessary to calculate the opposition of a branch resistor. Here's how.....

Each branch is connected to the power source. Therefore, each branch has the battery voltage as a voltage source. If the branch current is known, the branch resistance can be calculated, using Ohms's Law.

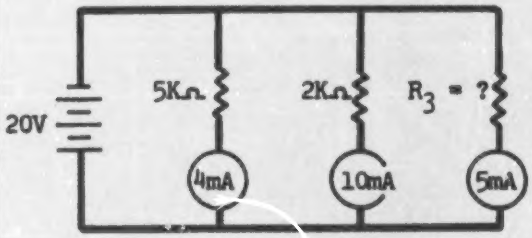
Equation $R = \frac{E}{I}$ $\text{BRANCH RESISTANCE} = \frac{\text{BRANCH VOLTAGE}}{\text{BRANCH CURRENT}}$

**EXAMPLE:** Calculate the opposition of $R_2$.

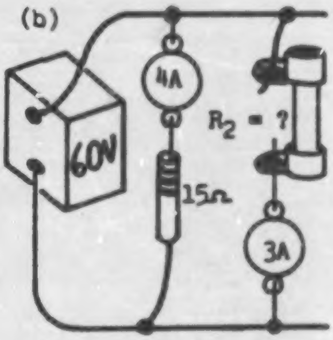


Q-10 Calculate branch resistances in the following circuits.

(a)



(b)



A-9

a. 3mA

b. 80mA

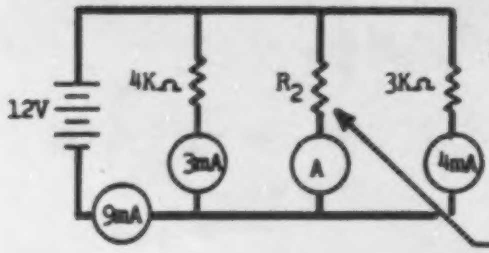
c. 3A

d. 15A

## CALCULATING BRANCH RESISTANCE (cont)

Sometimes, Kirchoff's Current Law and Ohm's Law, must be used together. More complex problems often require both laws.

EXAMPLE: Calculate the opposition of $R_2$.



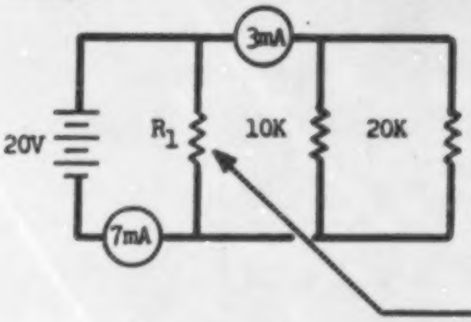
KIRCHOFF'S LAW

Since $I_t = 9mA$, $I_{R_2}$ must be 2mA

OHM'S LAW

$$R_2 = \frac{E_a}{I_{R_2}} = \frac{12V}{2mA} = 6K\Omega$$

EXAMPLE: Calculate the opposition of $R_1$.



KIRCHOFF'S LAW

Since $I_{R_2} + I_{R_3} = 3mA$....

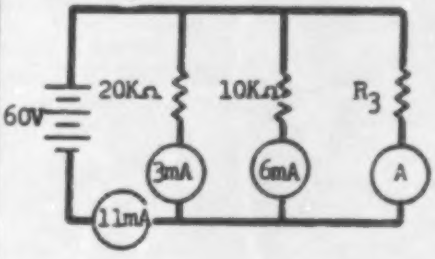
$I_{R_1}$ must be the other 4mA.

OHM'S LAW

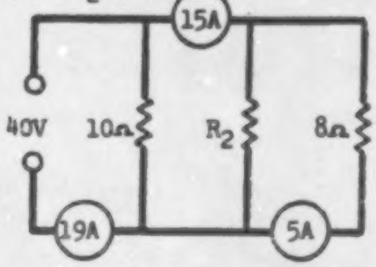
$$R_1 = \frac{E_a}{I_{R_1}} = \frac{20V}{4mA} = 5K\Omega$$

Q-11 Solve as indicated.

(a) $R_3 = ?$



(b) $R_2 = ?$

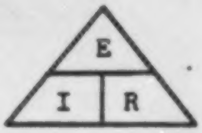


A-10 a. 4KΩ b. 20Ω

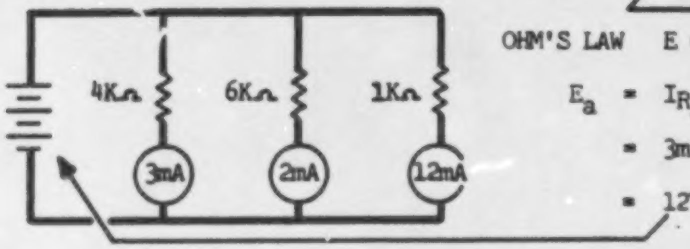
## CALCULATING THE APPLIED VOLTAGE

The Applied Voltage (battery), is usually known. If not, it can usually be "measured" with a voltmeter. However, it is possible for the points of measurement to be at difficult spots to get at, and a calculation becomes the best method.

The calculation is possible, if a branch current and resistance are known. Multiplication, using Ohm's Law, will result in the Applied Voltage ($E_a$).



**EXAMPLE:** Determine the Applied Voltage ($E_a$)



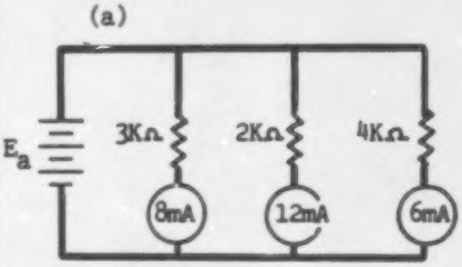
OHM'S LAW $E = I \cdot R$

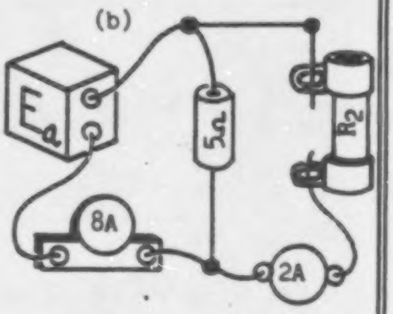
$$E_a = I_{R_1} \cdot R_1 = 3mA \cdot 4K\Omega = 12V$$

Either of the other two branches could have been used to determine the Applied Voltage. The calculations would result in the same voltage.

$$E_a = I_{R_2} \cdot R_2 = 2mA \cdot 6K\Omega = 12V$$
$$E_a = I_{R_3} \cdot R_3 = 12mA \cdot 1K\Omega$$

Q-12 Solve for the Applied Voltage.





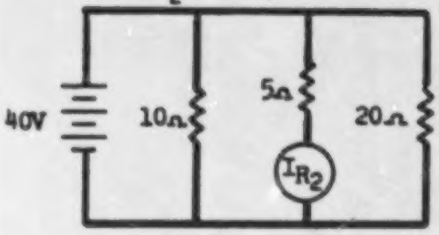
| | | |
|---|---|---|
| A-11 | a. 30KΩ | b. 4Ω |

PRACTICE PROBLEMS

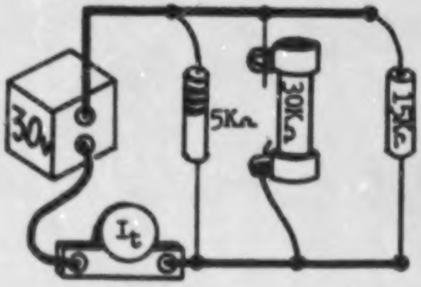
Using combinations of Kirchoff's Current Law and Ohm's Law, solve the following practice problems. The first step is to make sure of the "question". Then form a "plan of attack" toward the solution. Answers are listed as A-13.

Q-13 Solve as indicated.

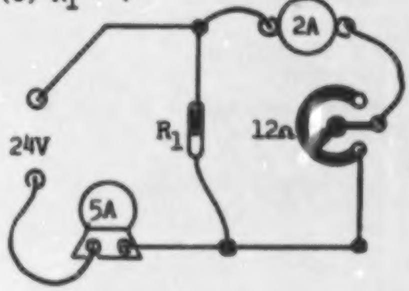
(a) $I_{R_2}$ = ?



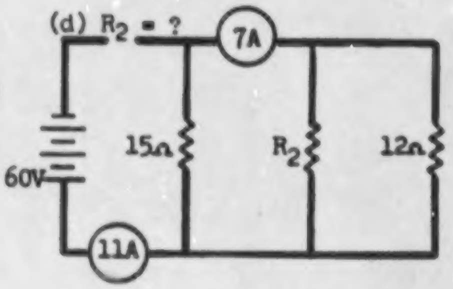
(b) $I_t$ = ?



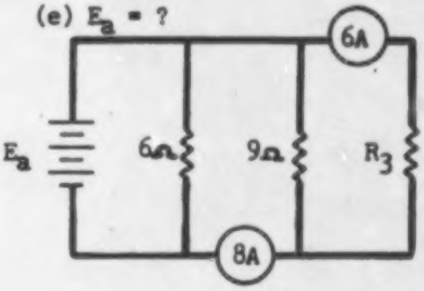
(c) $R_1$ = ?



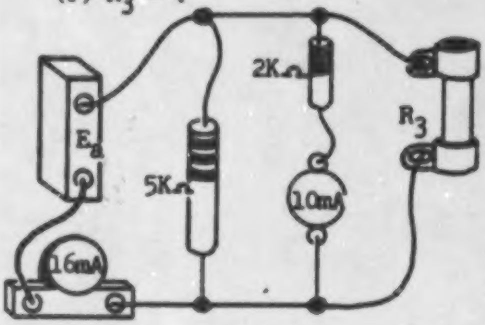
(d) $R_2$ = ?



(e) $E_a$ = ?



(f) $R_3$ = ?

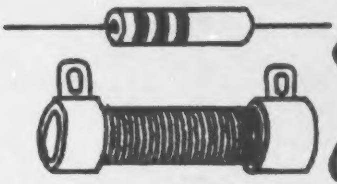


A-12
a. 24V b. 30V

ELECTRICAL POWER

The flow of electrons thru some type of opposition, produces heat. When electrical current flows thru a light-bulb, heat is generated. Soldering-irons depend upon this conversion of electrical energy into heat. The resistance wire, used in electric-toasters, is heated by the flow of large quantities of electrons.

Of course, resistors offer opposition to electrical current. and heat will be generated within them. With proper physical construction, the heat produced will not damage the resistors. However, this heat must be "gotten-rid-of" into the surrounding air. If not, the heat will continue to "build-up", until the resistor is damaged.



Carbon type resistors can withstand only small amounts of heat.

Wire-wound resistors are used when larger amounts of heat are involved.

The physical size of a resistor (its surface area), is the main factor which determines how much heat it can "dissipate" (get-rid-of). Therefore, carbon and wire-wound resistors have many different shapes and sizes. It is important to understand that the "physical size", has nothing to do with the resistance (ohms) of a resistor. The resistance depends upon the materials used "inside" the resistor.

Q-14 a. The flow of electrons thru some type of opposition, produces ________.
b. T-F Carbon resistors can withstand large amounts of heat.
c. T-F The physical size of a resistor determines resistance.
d. The main factor which determines the ability of a resistor to dissipate heat is its ______________ size.

650

A-13

a. 8A

b. 9mA

c. 8Ω

d. 30Ω

e. 18V

f. 10KΩ

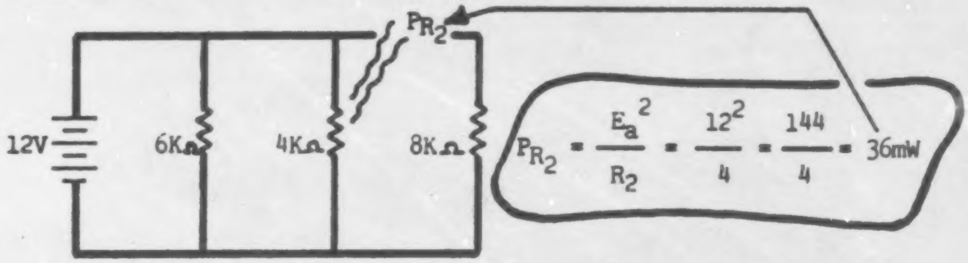
## CALCULATING POWER

The power dissipated by a resistor in a Parallel circuit, is calculated using any of the following equations. [Note that they are the same "power equations", used for Series circuits.]

Equations: $\boxed{P = I^2 \cdot R}$ $\boxed{P = \frac{E^2}{R}}$ $\boxed{P = E \cdot I}$

The unit of measure, is the Watt (W). If the current flow thru a resistor is in the smaller milli-ampere (mA), the power dissipated will be in the smaller milli-watt (mW).

EXAMPLE: Calculate the power dissipated by $R_2$.

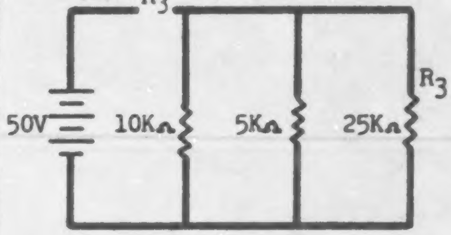


$$P_{R_2} = \frac{E_a^2}{R_2} = \frac{12^2}{4} = \frac{144}{4} = 36mW$$

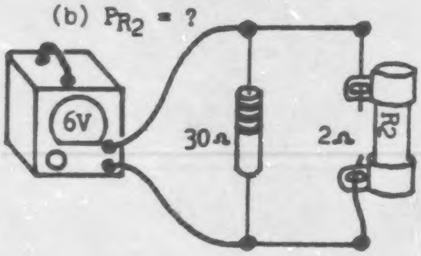
Of course, either of the other two power equations could have been used. The result, (36mW) would have been the same.

Q-15 Solve as indicated.

(a) $P_{R_3}$ = ?



(b) $P_{R_2}$ = ?



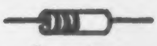
660

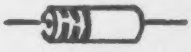
A-14
a. heat.
b. False....carbon would be damaged. Wire-wound are used.
c. False....the materials inside the resistor determine that.
d. Physical size (surface area)

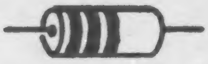
## POWER DISSIPATION vs POWER RATING

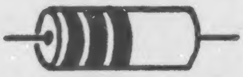
A resistor, in an operating circuit, will produce heat. This is called its POWER DISSIPATION. However, there is a limit to the amount of heat a particular resistor can withstand, without damage. This "limit" is called its POWER RATING.

The POWER RATING of a resistor is determined by its physical size (surface area). Carbon resistors are typically "rated at"......


¼ watt
(250mW)


½ watt
(500mW)

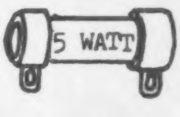

1 watt
(1000mW)

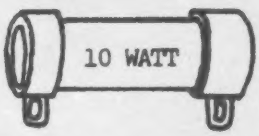

2 watt
(2000mW)

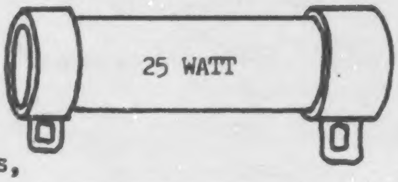
Suppose the power calculation for a resistor came out to be 1200mW. The smallest POWER RATING that could be used, would be the 2 watt (2000mW) size. Anything smaller would "burn-up".

If the power calculation came out to be 300mW, the minimum POWER RATING that could be used, would be the ½ watt (500mW) size.

Above 2 watts (2000mW), wire-wound resistors are employed. They are capable of withstanding greater amounts of heat.







The POWER RATING for the resistors, will be shown in the "parts list" accompanying the equipment.

Q-16
a. The heat given off by a resistor is called its power ________.
b. T-F Power dissipation is determined by the physical size of a resistor.
c. T-F The power rating of a resistor is determined by its physical size.
d. Never allow the power dissipation to be greater than the ________ ________.

A-15 a. 100mW b. 18W

## TOTAL POWER

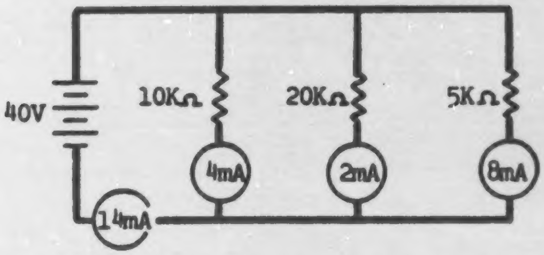
The Total Power ($P_t$), dissipated in a parallel circuit, is the SUM of the individual branch "powers".

**Equation** $\boxed{\text{TOTAL POWER } (P_t) = P_{R_1} + P_{R_2} + P_{R_3}}$

The Total Power ($P_t$), may also be calculated by multiplying the Applied Voltage ($E_a$) times the Total Current ($I_t$).

**Equation** $\boxed{\text{TOTAL POWER } (P_t) = E_a \bullet I_t}$

**EXAMPLE:** Calculate the Total Power ($P_t$) in the following circuit.



$P_t = E_a \cdot I_t$

$= 24V \cdot 14mA$

$= 560mW\ (.56W)$

$P_{R_1} = E_{R_1} \cdot I_{R_1} = 40V \cdot 4mA = 160mW\ (.16W)$

$P_{R_2} = E_{R_2} \cdot I_{R_2} = 40V \cdot 2mA = 80mW\ (.08W)$

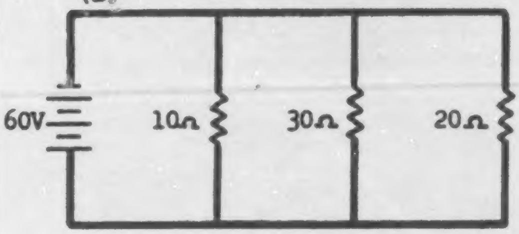
$P_{R_3} = E_{R_3} \cdot I_{R_3} = 40V \cdot 8mA = \underline{320mW\ (.32W)}$

$\boxed{P_t = P_{R_1} + P_{R_2} + P_{R_3}} = 560mW\ (.56W)$

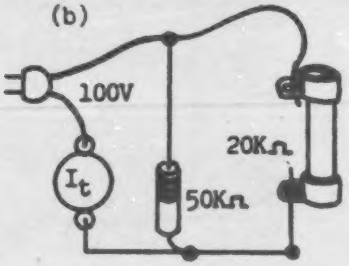
SAME ANSWER

Q-17 Solve for Total Power ($P_t$) in the following circuits.

(a)



(b)

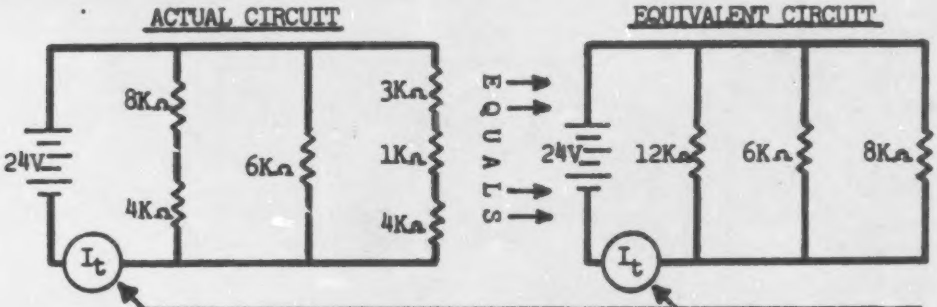


A-16
- a. dissipation. (The change of electrical energy into heat.)
- b. False.....the power dissipation is determined by the amount of current flowing thru the resistor.
- c. True
- d. power rating....otherwise the resistor will be damaged.

## COMPLEX PARALLEL

In some parallel circuits, the branches may have more than one resistor. The resistance of each branch is determined thru addition.

**EXAMPLE:** Calculate the Total Current ($I_t$) in the following circuit.



Dividing $E_a$ (24V) by the resistance (12KΩ) of branch one = 2mA

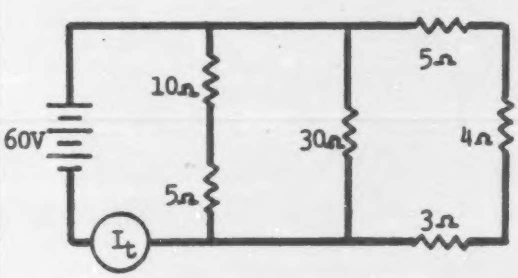
Dividing $E_a$ (24V) by the resistance ( 6KΩ) of branch two = 4mA

Dividing $E_a$ (24V) by the resistance ( 8KΩ) of branch three = 3mA

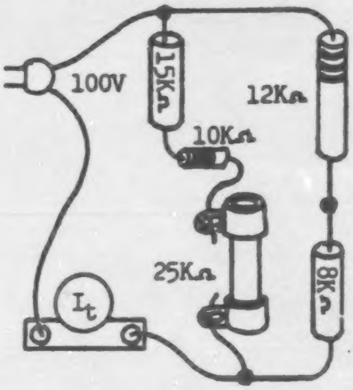
**Answer** = Adding the three branch currents together = 9mA

Q-18 Solve for the Total Current ($I_t$) in the following circuits.

(a)



(b)



| A-17 | a. 660W | b. 700mW (.7W) |
|---|---|---|

COMPLEX PARALLEL (cont)

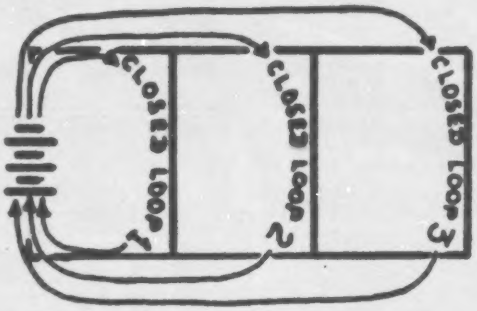
Kirchoff's Voltage Law states [in effect]:

**Kirchoff's Voltage Law**

> The sum of the voltage drops,
> in a closed loop,
> equals the applied voltage.

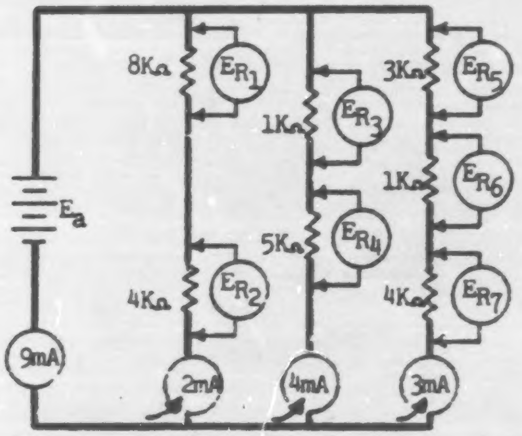
In a parallel circuit, each branch is a "closed loop".

Each branch forms a CLOSED LOOP with the battery.



In a complex parallel circuit, there will be more than one voltage drop in each branch. There will be a voltage drop across each resistor. Therefore, the sum of the voltage drops in each branch must equal the battery voltage.

EXAMPLE: Determine the Applied Voltage ($E_a$)



BATTERY VOLTAGE

$$\left.\begin{aligned} E_{R_1} &= I_{R_1} \cdot R_1 = 16V \\ E_{R_2} &= I_{R_2} \cdot R_2 = 8V \end{aligned}\right\} 24V$$

$$\left.\begin{aligned} E_{R_3} &= I_{R_3} \cdot R_3 = 4V \\ E_{R_4} &= I_{R_4} \cdot R_4 = 20V \end{aligned}\right\} 24V$$

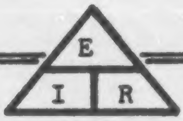
$$\left.\begin{aligned} E_{R_5} &= I_{R_5} \cdot R_5 = 9V \\ E_{R_6} &= I_{R_6} \cdot R_6 = 3V \\ E_{R_7} &= I_{R_7} \cdot R_7 = 12V \end{aligned}\right\} 24V$$

Q-19 a. Kirchoff's Voltage Law states....The sum of the voltage drops in a _______ _______ equals the applied voltage.

A-18 a. 11A b. 7mA

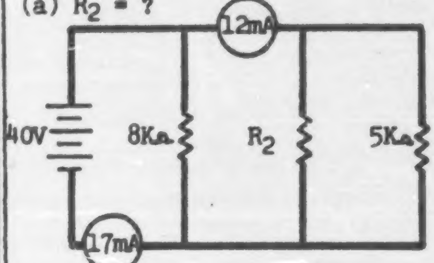
PRACTICE PROBLEMS

Using combinations of Ohm's Law, Kirchoff's Current Law, and Kirchoff's Voltage Law, solve the following problems. The first step is to make sure of the question. Then form a "plan of attack" toward the solution. Answers are listed as A-20.

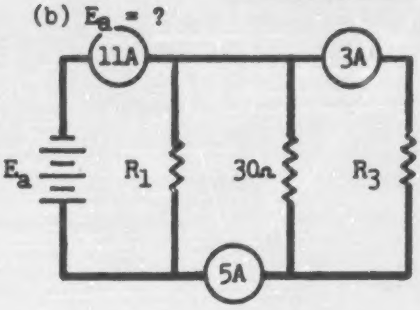


Q-20 Solve as indicated.

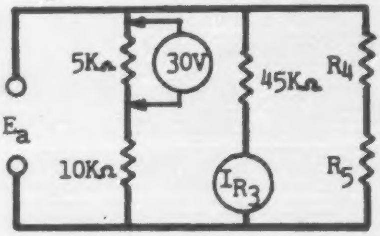
(a) $R_2$ = ?



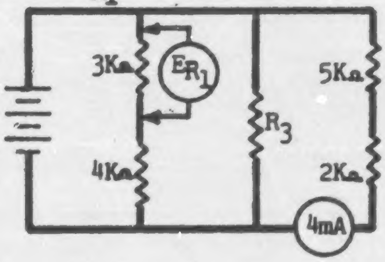
(b) $E_a$ = ?



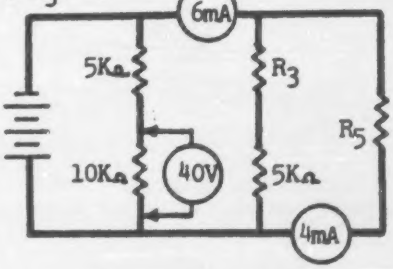
(c) $I_{R_3}$ = ?



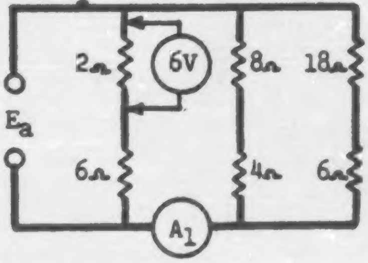
(d) $E_{R_1}$ = ?



(e) $R_3$ = ?



(f) $A_1$ = ?



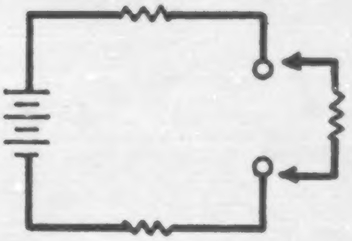
A-19 a. "closed loop"

## TOTAL RESISTANCE

A group of resistors, connected in parallel with a battery, serves no useful purpose. It simply wears out the battery. As each parallel branch is added, more current is allowed to flow out of the battery, wearing it out sooner.

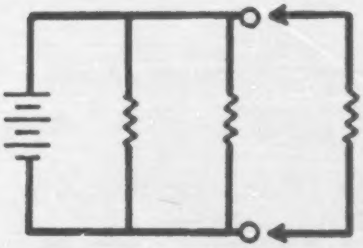
It may be recalled from the beginning of this text, that entire electronic circuits are connected in parallel with a power source. Resistors have been used to clarify the principles of parallel operation, and to simplify calculations.

However, actual resistors may be connected directly in parallel with each other. This is sometimes done to form a particular "total resistance" needed in a special situation. Solving for this parallel "total resistance" is NOT done the same way as in Series Circuits.



Adding another resistor into a Series circuit DECREASES the amount of current allowed to flow out of the battery.

This reduction of current means that the total opposition of the circuit must have INCREASED. $R_t$↑



Adding another resistor into a Parallel circuit INCREASES the amount of current allowed to flow out of the battery.

This increase of current means that the total opposition of the circuit must have DECREASED. $R_t$↓

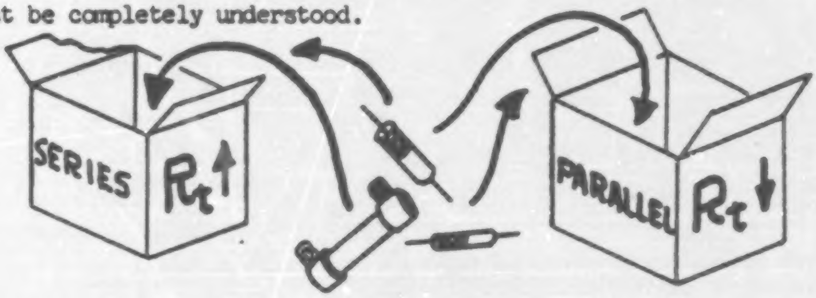
Q-21 a. If another resistor is added into a series circuit, the total current ________, therefore the total resistance must have ________________. (Inc-dec)

b. Adding another resistor in parallel will cause total current to ____________ and total resistance to ________.

A-20 a. 10KΩ c. 2mA e. 25KΩ
b. 60V d. 12V f. 3A

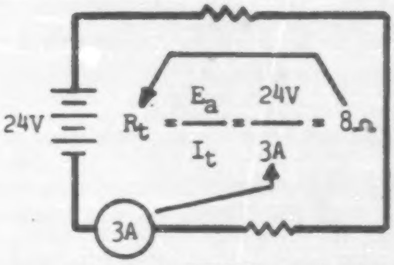
## TOTAL RESISTANCE (cont)

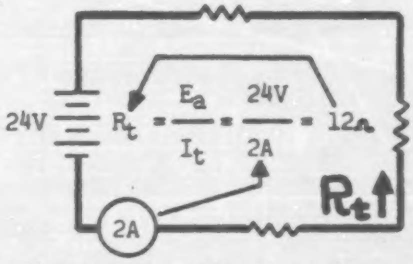
This MAJOR DIFFERENCE between Series and Parallel circuits, must be completely understood.



Perhaps a couple of simple problems may help to understand what's going on here.

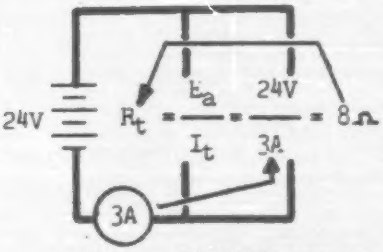
SERIES

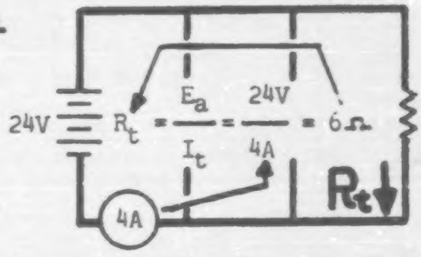




Adding a SERIES resistor, decreases the current allowed to flow. Therefore.....OPPOSITION to the flow of current has INCREASED!

PARALLEL





Adding a PARALLEL resistor, increases the current allowed to flow. Therefore.....OPPOSITION to the flow of current has DECREASED!

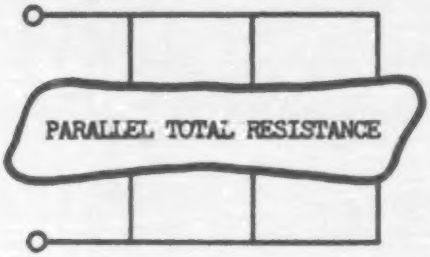
Q-22 a. If another parallel branch is added, the total current will ____________, therefore resistance must have ________.
b. The total resistance of a parallel circuit ______(inc-dec) as each branch is added.
c. Increasing total resistance, _____ (inc-dec) total current.

A-21 a. decreases, increased......any time the total current decreases, the total resistance must have increased.

b. increase, decrease.....any time the total current increases the total resistance must have decreased.

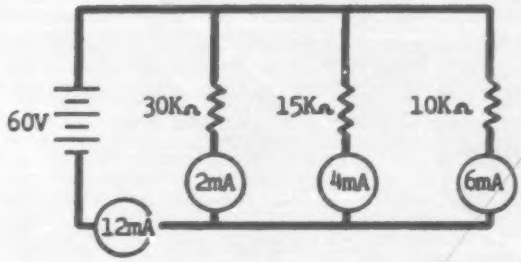
## CALCULATING TOTAL RESISTANCE

There are several different methods which can be used to calculate the Total Resistance ($R_t$) of a parallel circuit. Any of these methods will result in the same answer. Which method is used, depends upon the circuit itself, and personal preference.



1. Ohm's Law
2. R over N Method
3. Product over Sum
4. Reciprocal Method

**EXAMPLE:** (Ohm's Law Method) Calculate the Total Resistance ($R_t$).



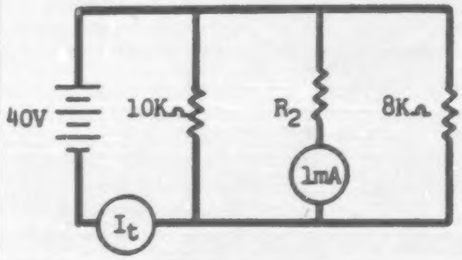
$$I_{R_1} = 2mA$$
$$I_{R_2} = 4mA$$
$$I_{R_3} = 6mA$$
$$I_t = 12mA$$

$$R_t = \frac{E_a}{I_t} = \frac{60V}{12mA}$$
$$R_t = 5K\Omega$$

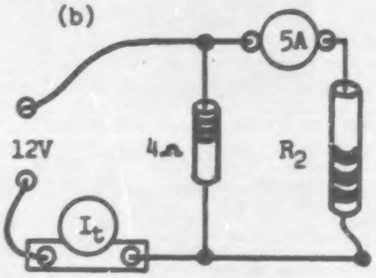
**NOTE:** The Total Resistance ($R_t$) is smaller than any "branch".

Q-23 Determine the Total Resistance ($R_t$) of the following.

(a)



(b)



A-22
a. increase, decreased
b. decreases......each branch causes a rise of total current. More total current means the resistance of the circuit must have decreased.
c. decreases

## CALCULATING TOTAL RESISTANCE (cont)

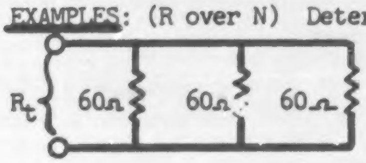
The "R over N" method is used when a group of parallel resistors all have the same opposition.

"R" stands for the COMMON RESISTANCE.

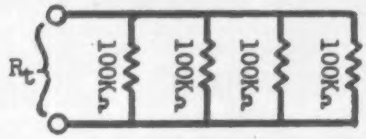
"N" stands for the NUMBER OF RESISTORS.

$$\frac{R}{N}$$

EXAMPLES: (R over N) Determine the Total Resistance ($R_t$).



$$R_t = \frac{R}{N} = \frac{\text{Common Resistance}}{\text{Number of Resistors}} = \frac{60\Omega}{3} = 20\Omega$$

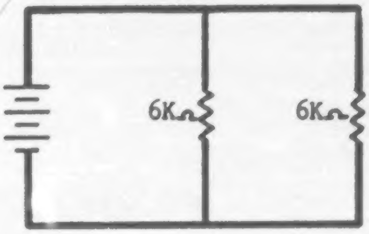


$$R_t = \frac{R}{N} = \frac{\text{Common Resistance}}{\text{Number of Resistors}} = \frac{100K\Omega}{4} = 25K\Omega$$

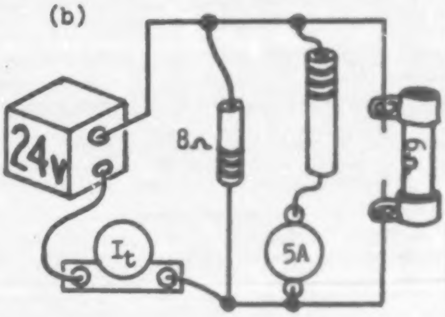
NOTE: The Total Resistance ($R_t$) is smaller than any "branch".

Q-24 Using Ohm's Law, or R over N, calculate Total Resistance ($R_t$).

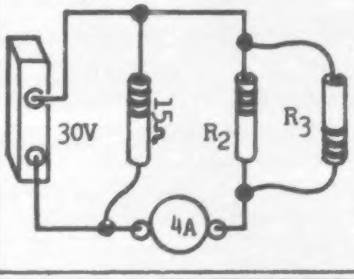
(a)



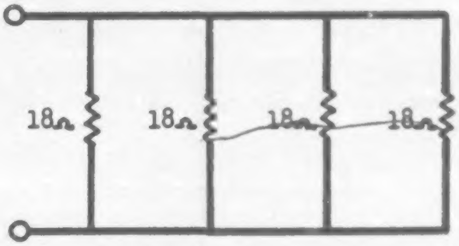
(b)



(c)



(d)



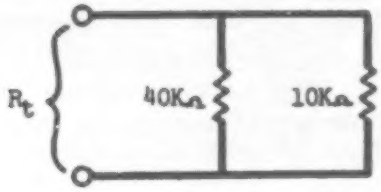
A-23 a. 4KΩ b. 1.5Ω

## CALCULATING TOTAL RESISTANCE (cont)

The "Product over Sum" method is used when two parallel resistors have different, or "unusual" resistance values.

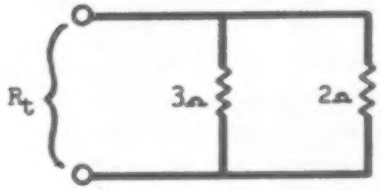
$$R_t = \frac{\text{Product}}{\text{Sum}} = \frac{R_1 \cdot R_2 \quad \text{[Multiplication]}}{R_1 + R_2 \quad \text{[Addition]}}$$

**EXAMPLES**: (Product over Sum) Calculate the Total Resistance ($R_t$).



$$R_t = \frac{\text{Product [Multiplication]}}{\text{Sum [Addition]}}$$

$$R_t = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{40 \cdot 10}{40 + 10} = \frac{400}{50} = 8\text{K}\Omega$$



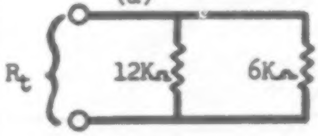
$$R_t = \frac{\text{Product [Multiplication]}}{\text{Sum [Addition]}}$$

$$R_t = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{3 \cdot 2}{3 + 2} = \frac{6}{5} = 1.2\Omega$$

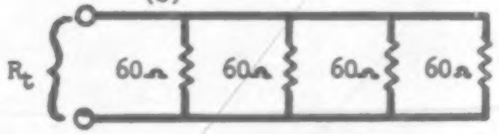
**NOTE**: The Total Resistance ($R_t$) is smaller than any "branch".

Q-25 Using Ohm's Law, R over N, or the Product over Sum methods, calculate the Total Resistance ($R_t$) of the following circuits.

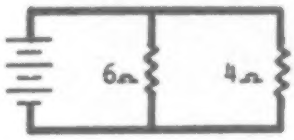
(a)



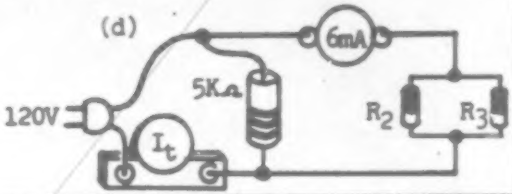
(b)



(c)



(d)



| A-24 | a. 3K$\Omega$ | b. 2$\Omega$ | c. 5$\Omega$ | d. 4.5$\Omega$ |
|---|---|---|---|---|

## CALCULATING TOTAL RESISTANCE (cont)

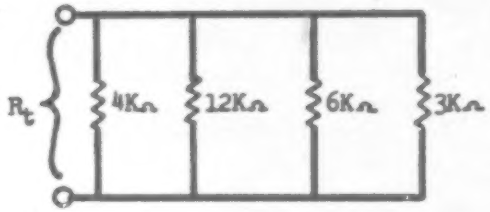
The "Reciprocal" method is used when a group of parallel resistors have a "common denominator". A "common denominator" is a number, into which each of the resistance values can be divided evenly. The "common denominator" for 4, 12, 6, and 3 would be 12, or 24, or 36 etc.. Usually, the "least common denominator" is used. In this case, that would be 12.

The "Reciprocal" equation appears difficult. It is however, easy to use.

EXAMPLE: (Reciprocal Method)

Equation

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \text{ etc.}}$$



HERE'S WHAT TO DO

$$\frac{1}{4} + \frac{1}{12} + \frac{1}{6} + \frac{1}{3}$$

① Resistance values (Drop "K")

$$\frac{3 + 1 + 2 + 4}{12}$$

Common Denominator

② Divide 4 into 12
12 into 12
6 into 12
3 into 12

$$\frac{10}{12}$$

③ Add

$$\frac{10}{12} \quad \frac{12}{10} = 1.2K\Omega\ (R_t)$$

④ Turn upside-down and divide. (Replace "K")

Q-26 Determine the "least common denominator" for the following.
(a) 6, 5, 15, 10 (b) 20, 15, 30 (c) 2, 8, 12, 6

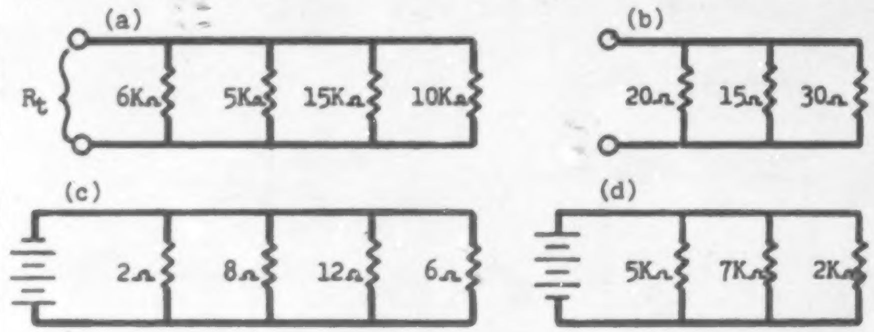
A-25
a. 4KΩ  b. 15Ω  c. 2.4Ω  d. 4KΩ

CALCULATING TOTAL RESISTANCE (cont)

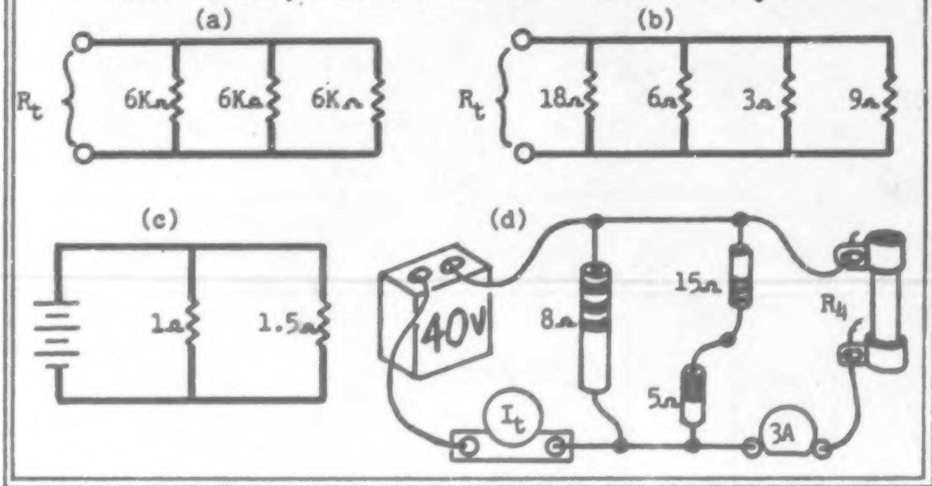
The "Reciprocal" method can be used with any number of parallel resistors. A common denominator must be determined first.

If "all else fails", a common denominator can be determined by multiplying all the resistance values together. This usually results in a rather large common denominator, difficult to use.

Q-27 Using the "Reciprocal" method, determine Total Resistance.



Q-28 Using Ohm's Law, R over N, Product over Sum, or the Reciprocal methods, calculate the Total Resistance ($R_t$).



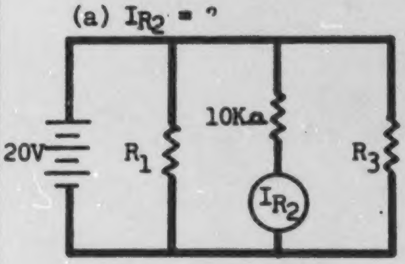
| A-26 | a. 30 | b. 60 | c. 24 |
|---|---|---|---|

## PRACTICE PROBLEMS

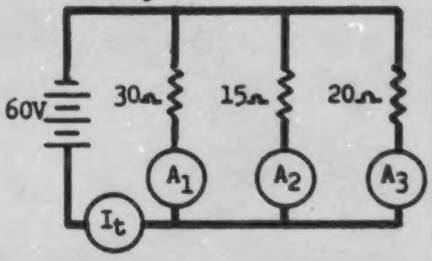
All of the Parallel Circuit skills that have been learned, will be required in the following practice problems. The first step is to make sure of the "question". Then form a "plan of attack" toward the solution. The problems will progress from simple to complex. A list of Ohm's Law, Power, and Parallel Circuit Equations may help in solving them quickly and easily.

Q-29 Solve as indicated.

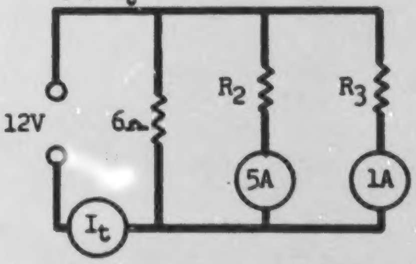
(a) $I_{R_2}$ = ?



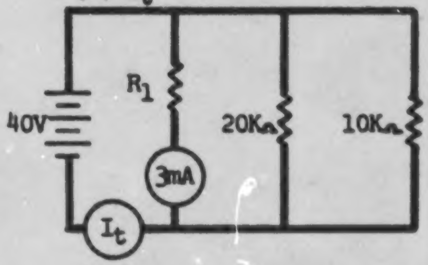
(b) $I_t$ = ?



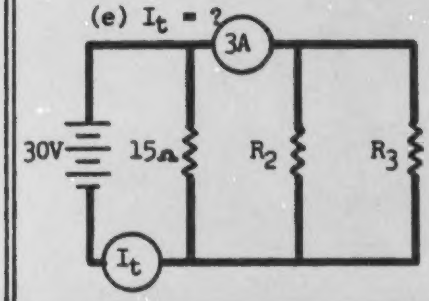
(c) $I_t$ = ?



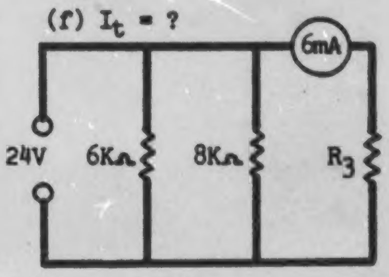
(d) $I_t$ = ?



(e) $I_t$ = ?



(f) $I_t$ = ?



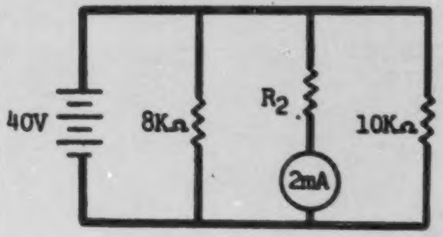
A-27 a. 1.87KΩ b. 6.66Ω c. 1.14Ω d. 1.18KΩ

A-28 a. 2KΩ b. 1.5Ω c. .6Ω d. 4Ω

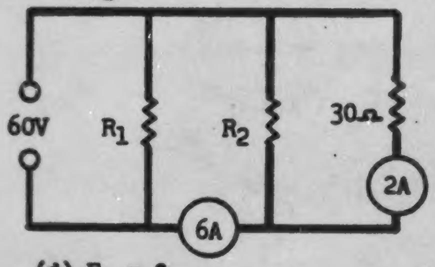
PRACTICE PROBLEMS (cont)

Q-30 Solve as indicated.

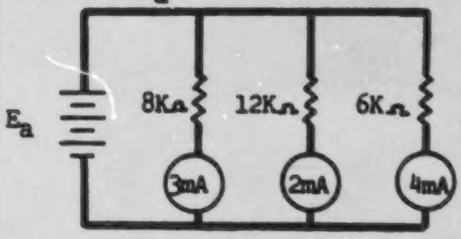
(a) $R_2$ = ?



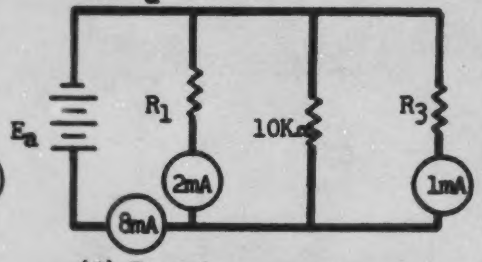
(b) $R_2$ = ?



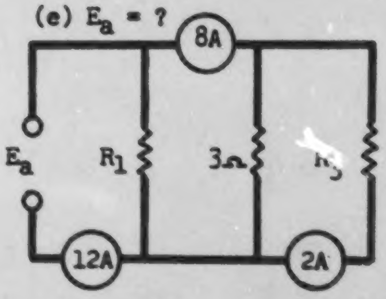
(c) $E_a$ = ?



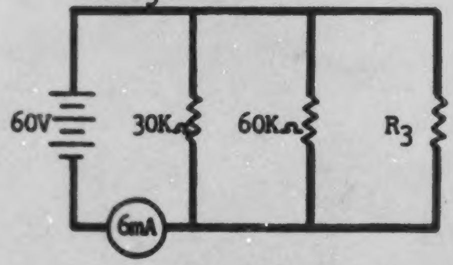
(d) $E_a$ = ?



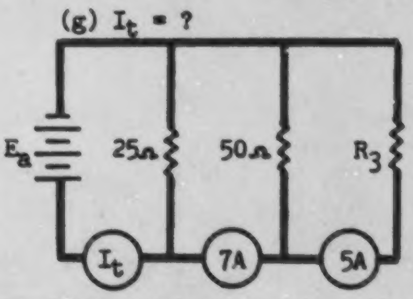
(e) $E_a$ = ?



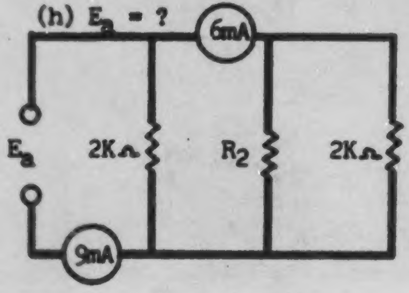
(f) $R_3$ = ?



(g) $I_t$ = ?



(h) $E_a$ = ?

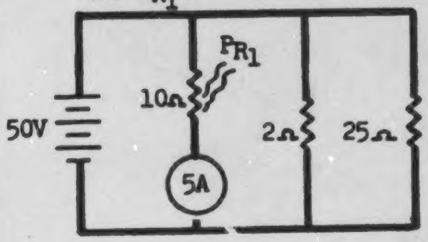


| A-29 | a. 2mA | c. 8A | e. 5A |
|---|---|---|---|
| | b. 9A | d. 9mA | f. 13mA |

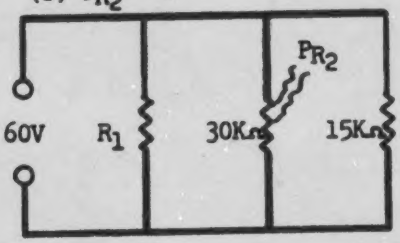
PRACTICE PROBLEMS (cont)

Q-31 Solve as indicated.

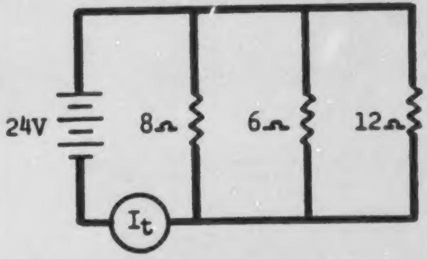
(a) $P_{R_1} = ?$



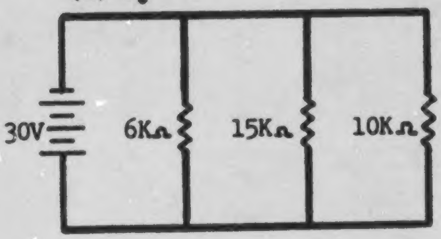
(b) $P_{R_2} = ?$



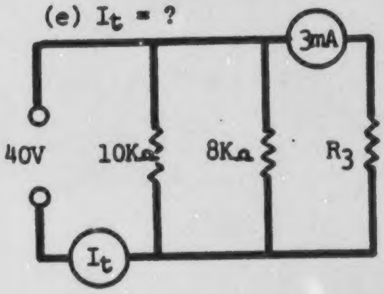
(c) $P_t = ?$



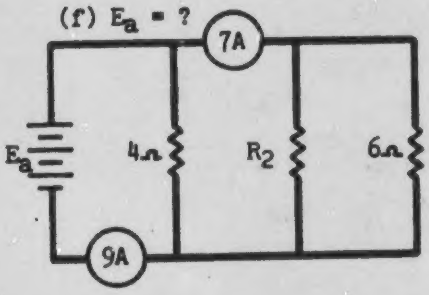
(d) $P_t = ?$



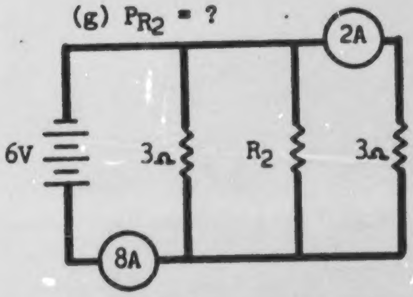
(e) $I_t = ?$



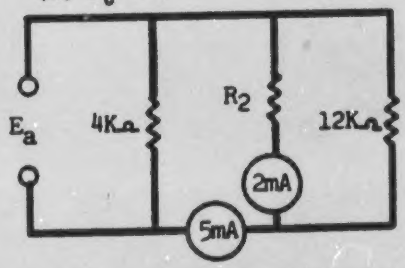
(f) $E_a = ?$



(g) $P_{R_2} = ?$



(h) $P_t = ?$

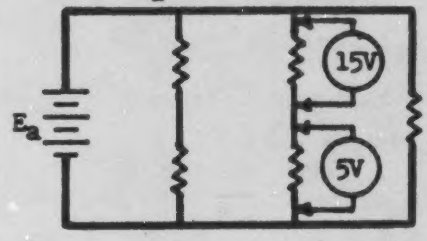


A-30
a. 20KΩ
b. 15Ω
c. 24V
d. 50V
e. 18V
f. 20KΩ
g. 11A
h. 6V

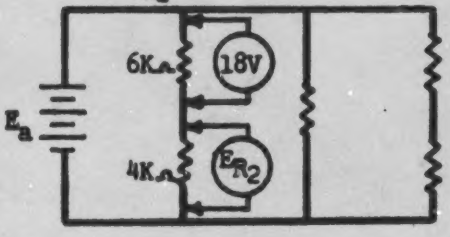
## PRACTICE PROBLEMS (cont)

Q-32 Solve as indicated.

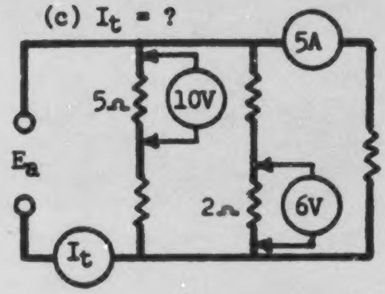
(a) $E_a$ = ?



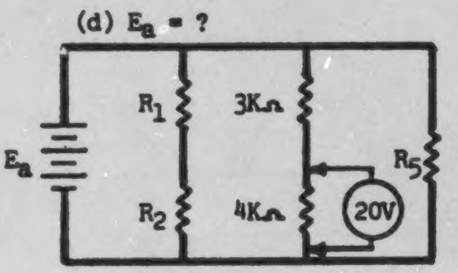
(b) $E_{R2}$ = ?



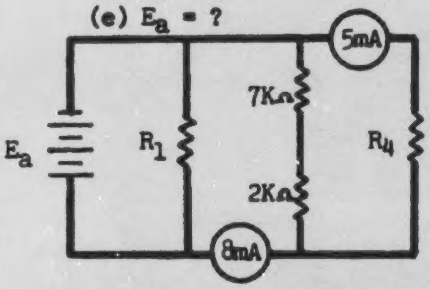
(c) $I_t$ = ?



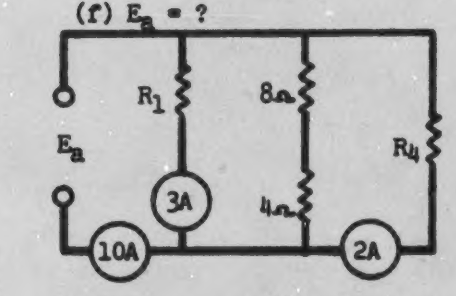
(d) $E_a$ = ?



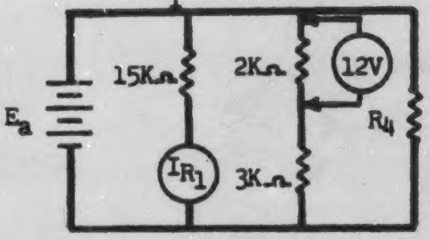
(e) $E_a$ = ?



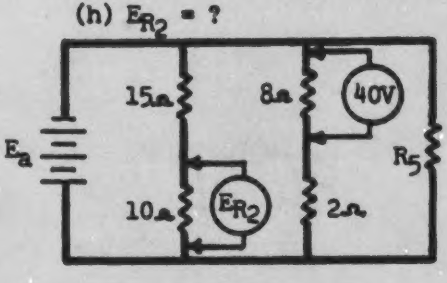
(f) $E_a$ = ?



(g) $I_{R_1}$ = ?



(h) $E_{R2}$ = ?

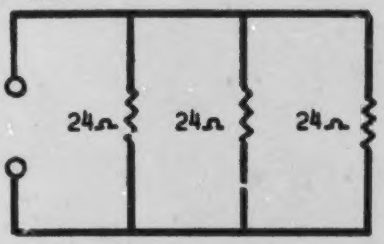


| | | | | |
|---|---|---|---|---|
| A-31 | a. 250W | c. 216W | e. 12mA | g. 24W |
| | b. 120mW (.12W) | d. 300mW (.3W) | f. 8V | h. 504mW |

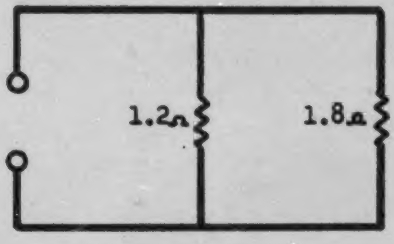
**PRACTICE PROBLEMS** (cont)

Q-33 Solve for Total Resistance ($R_t$).
**NOTE**: The Total Resistance ($R_t$), is smaller than any branch.

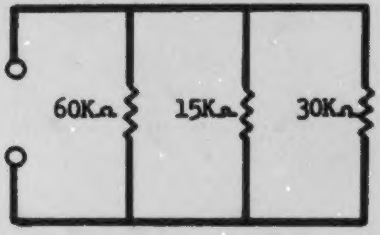
(a)



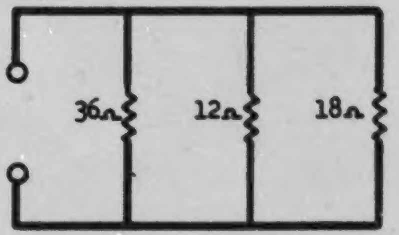
(b)



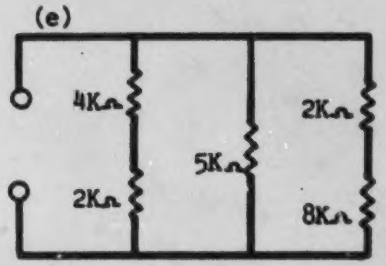
(c)



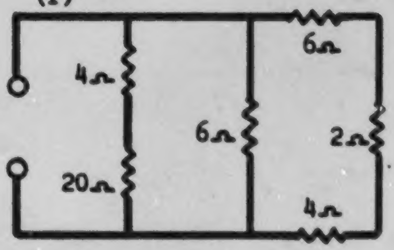
(c)



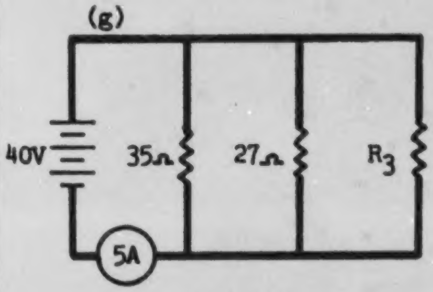
(e)



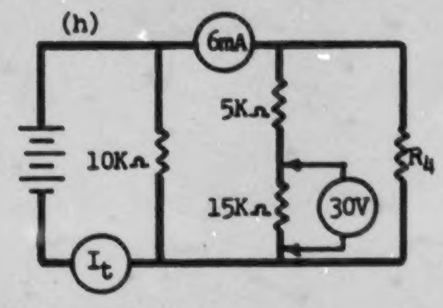
(f)



(g)



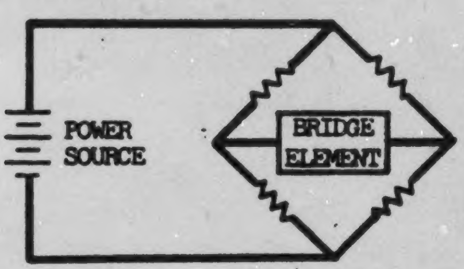
(h)



| A-32 | | | | |
|---|---|---|---|---|
| | a. 20V | c. 10A | e. 27V | g. 2mA |
| | b. 12V | d. 35V | f. 60V | h. 20V |

## RESISTIVE BRIDGE CIRCUITS

A special complex parallel circuit is called a "Bridge Circuit". It consists of four resistors, connected into a "diamond" shape. There is an additional component called the "bridge element".

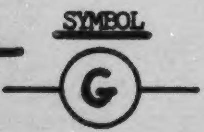


**BRIDGE ELEMENT**

In many applications, the "bridge element" is a resistor. Special electrical components are also used.

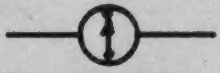
## GALVANOMETER [gal-va-noḿ-e-ter]

Sometimes, the "bridge element" is a Galvanometer. This is a sensitive ampere-meter, with "zero" in the middle of the scale. It can measure current flowing in either direction.

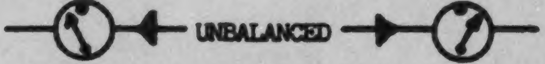


## BALANCED OR UNBALANCED

If the Galvanometer is pointing to "zero" (no current), the Bridge Circuit is said to be "BALANCED".



If the Galvanometer is indicating current flow, in either direction, the Bridge Circuit is said to be "UNBALANCED".



Like an acrobat, on a tightrope, a Bridge Circuit can only be in one of two possible conditions: BALANCED, or UNBALANCED.

Q-34 a. An ammeter, with "zero" in the middle of the scale, is called a ______________.
b. Bridge Circuits can be balanced or ________________.

| A-33 | | | | |
|---|---|---|---|---|
| | a. 8Ω | c. 8.57KΩ | e. 2.14KΩ | g. 8Ω |
| | b. .72Ω | d. 6Ω | f. 3.42Ω | h. 4KΩ |

BRIDGE CIRCUITS (cont)

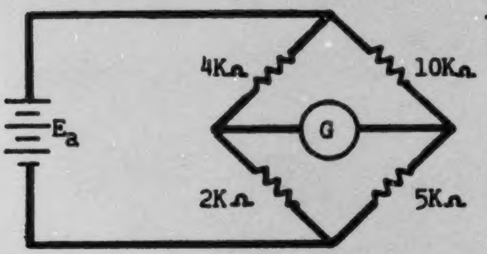
A Bridge Circuit may be in a "balanced" or an "unbalanced" condition. It depends upon the resistance (ohms) of each of the four "bridge" resistors.

To determine a "balanced" or "unbalanced" condition, the BRIDGE CIRCUIT EQUATION is used.

*Equation*

$$\frac{R_1 \text{ [Upper Left]}}{R_2 \text{ [Lower Left]}} = \frac{R_3 \text{ [Upper Right]}}{R_4 \text{ [Lower Right]}}$$

**EXAMPLE:** Is the following circuit "balanced" or "unbalanced"?

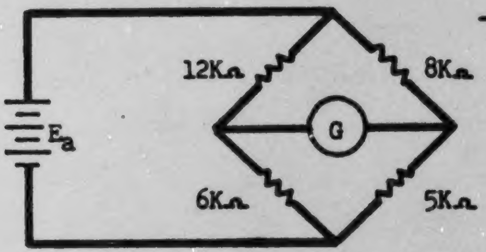


$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \frac{4}{2} = \frac{10}{5}$$

"Cross-multiply" $$\frac{4}{2} = \frac{10}{5}$$

BALANCED ⟶ 20 = 20

**EXAMPLE:** Is the following circuit "balanced" or "unbalanced"?



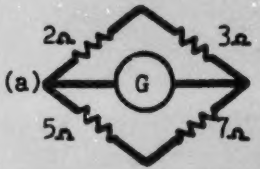
$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \frac{12}{6} = \frac{8}{5}$$

"Cross-multiply" $$\frac{12}{6} = \frac{8}{5}$$

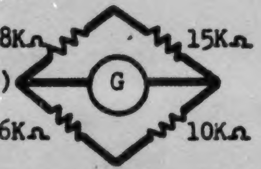
UNBALANCED ⟶ 48 = 60

Q-35 Are the following circuits "balanced" or "unbalanced"?

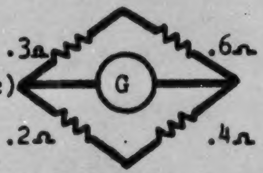
(a)



(b)



(c)

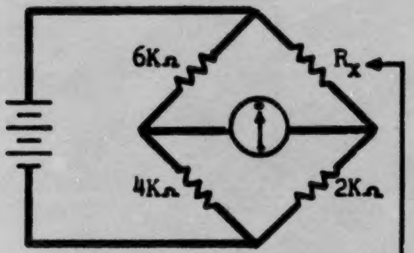


A-34
- a. Galvanometer.
- b. unbalanced.

## BRIDGE CIRCUITS (cont)

If one of the resistors in a "balanced" bridge circuit is unknown, it can be easily calculated. The BRIDGE CIRCUIT EQUATION is used to determine the unknown resistance value.

**EXAMPLE:** Calculate $R_x$ in the following "balanced" Bridge Circuit.



$$\frac{R_1}{R_2} = \frac{R_x}{R_4} \qquad \frac{6}{4} = \frac{x}{2}$$

"Cross-multiply" $\frac{6}{4} = \frac{x}{2}$

Divide both sides of the equation by 4 for answer.

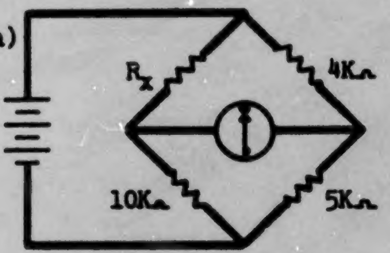
$4x = 12$

$x = 3\text{K}\Omega$

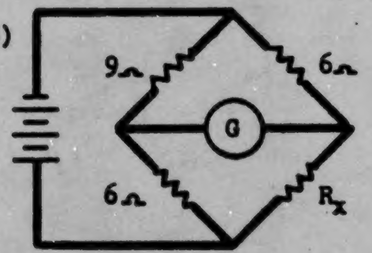
**NOTE:** $R_x$ has to be 3KΩ. No other resistor will "balance" the Bridge Circuit. Easy? Try these......

Q-36 Calculate $R_x$ in the following "balanced" Bridge Circuits.

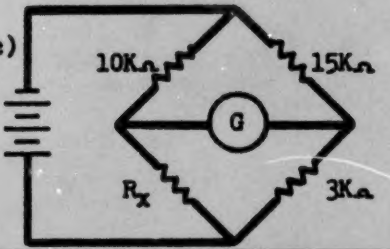
(a)



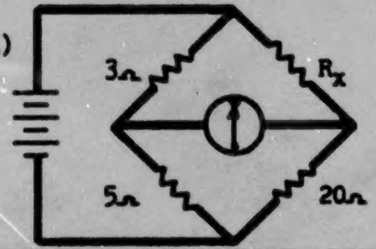
(b)



(c)



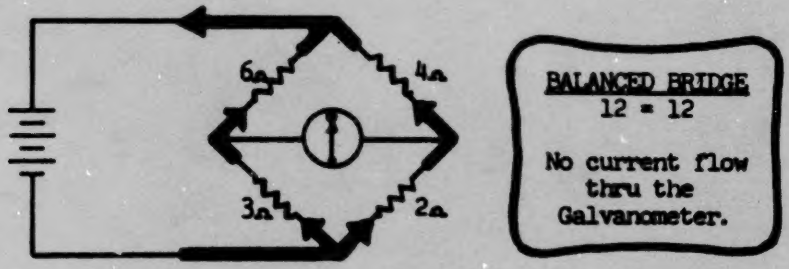
(d)



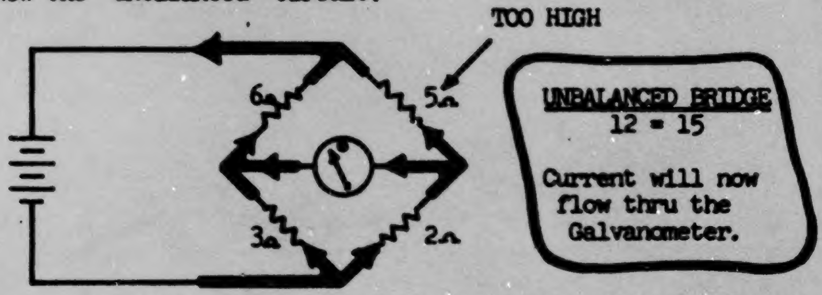
A-35 a. Unbalanced b. Unbalanced c. Balanced

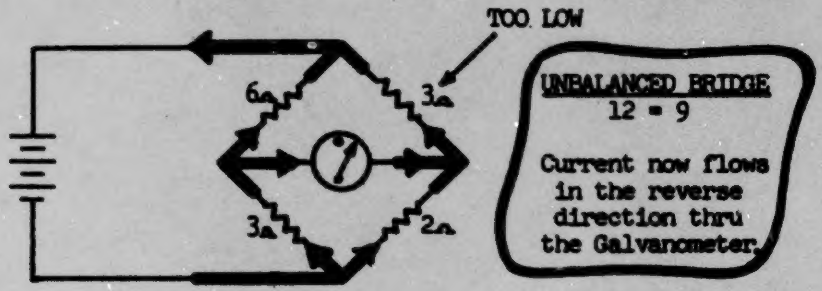
## BRIDGE CIRCUIT CURRENTS

The electrical currents flowing thru a Bridge Circuit, depend upon a "balanced" or "unbalanced" condition. First the "balanced" circuit.



Now the "unbalanced" circuit.




TOO LOW
6Ω
3Ω
3Ω
2Ω
UNBALANCED BRIDGE
12 = 9
Current now flows in the reverse direction thru the Galvanometer.

If the "polarity" of the battery is reversed, the direction of current thru the Galvanometer would also reverse.

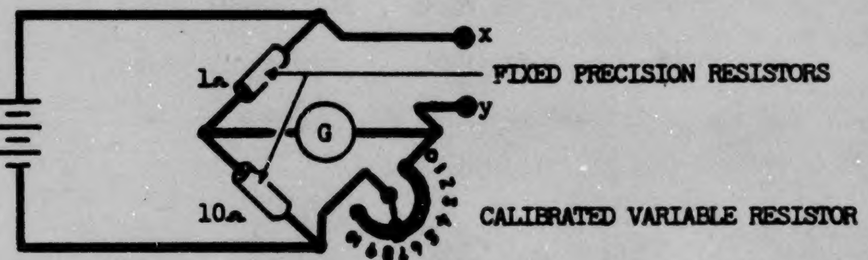
Q-37 a. If the Galvanometer is indicating current, the bridge circuit is ______________(balanced or unbalanced)
b. T-F Varying any resistor in a balanced bridge circuit, will cause current flow thru the bridge element.

| A-36 | | | |
|---|---|---|---|
| a. 8KΩ | b. 4Ω | c. 2KΩ | d. 12Ω |

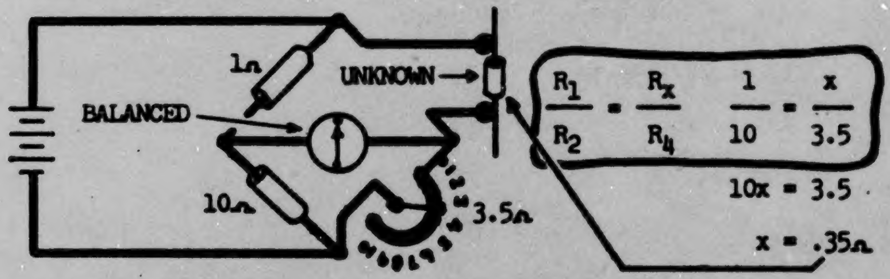
## USES OF BRIDGE CIRCUITS (Wheatstone Bridge)

In some Electronic circuits, "precision resistors" are used. These resistors have been very accurately measured. The ohmic value is printed directly on the body of the resistor.

A device used to measure these critical resistance values is called the Wheatstone Bridge. In it's simplest form, it consists of two fixed "precision resistors", and one variable resistor. The variable resistor has a "calibrated" scale attached to it.



The resistor to be measured is connected between points [x & y]. The variable resistor is rotated until the Bridge Circuit is "balanced" (no Galvanometer current). The "bridge equation" is then used to determine the accurate value of the unknown resistor.



$$\frac{R_1}{R_2} = \frac{R_x}{R_4} \qquad \frac{1}{10} = \frac{x}{3.5}$$

$$10x = 3.5$$

$$x = .35\Omega$$

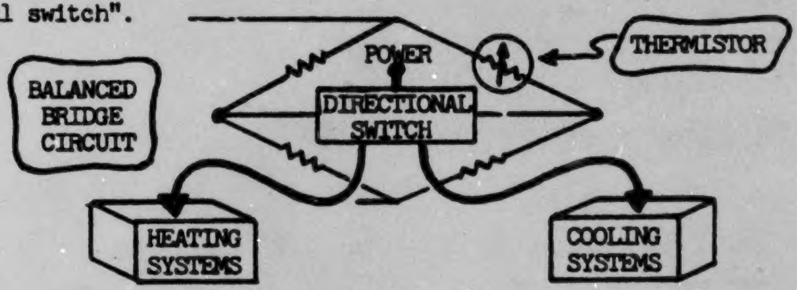
More advanced Wheatstone Bridges will have a series of fixed precision resistors, or "calibrated resistance bars", which can be plugged-into the $R_1$ and $R_2$ positions. The $R_4$ position may be occupied by a group of "switchable" fixed precision resistors, called a Decade Resistance Assembly.

A-37 a. unbalanced......and if the Galvanometer is a VERY sensitive one, only a slight variation of one of the resistors will cause a large meter deflection.
b. True.....see answer above.

USES OF BRIDGE CIRCUITS (Temperature Control)

A "thermistor" is a special type of resistor. It's resistance (ohms) varies with changes of temperature. A "directional-switch", is a special two-way switch, something like an automobile turn-signal switch, operated electrically.

In the $R_3$ position of a "balanced" bridge circuit, substitute a "thermistor". In the bridge-element position, place a "directional switch".



If the temperature changes, the resistance of the thermistor changes, "unbalancing" the bridge. The directional-switch then connects electrical power to either the heating, or cooling systems.

As the temperature returns to normal, the resistance of the thermistor restores the bridge to a "balanced" condition. The directional-switch then returns to a "neutral" position, (no power to either system).

The "balance temperature" is adjusted with one of the other bridge resistors, made variable and calibrated in degrees.

By replacing the "thermistor" with an appropriate sensing device, many other "control systems" can be developed.

## SUMMARY

Furthur study of Parallel Resistive Circuits and Bridge Circuits, can be made thru the many advanced publications available in Technical Library Centers.

The principles of parallel operation learned here, will be used throughout Electronics training. All advanced circuits use the parallel connection to provide a common power source for their operation. Resistors connected in parallel, can produce a special resistance value needed in some applications.

The flow of parallel currents thru "branches", and the formation of a "total current", will be again studied in many of the circuit types to come. An understanding of these "currents" is essential to the location of circuit "troubles", which cause these currents to change.

Bridge Circuits, balanced and unbalanced, form the center of many types of test-equipment to be used in calibration and troubleshooting. They are used in complex Electronic circuits of all kinds. Transmitters, Receivers, and Control Systems often employ the principles of Bridge Circuits in unusual ways.

Parallel Resistive Circuits.....SIDE-BY-SIDE in Electronics!!

NOTES

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-8

Technical Training

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## MODULE 8

## PARALLEL RESISTIVE CIRCUITS

November 1975

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## MODULE 8

## PARALLEL RESISTIVE CIRCUITS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

| TITLE | PAGE |
|---|---|
| Overview | 1 |
| List of Resources | 1 |
| Adjunct Guide | 1 |
| Module Self-Check | 5 |
| Answers | 6 |

## OVERVIEW

1. SCOPE: It is often necessary to connect several electrical devices across a single power source so the full voltage of the power source is across each device. Such a circuit is a parallel circuit. This module discusses Kirchhoff's law and applies it to a parallel circuit. You will solve DC parallel resistive circuit problems for resistance, current, and power.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a group of statements, select the ones that describe Kirchhoff's law for current and for voltage.

b. Given a parallel circuit schematic diagram and formulas, solve for:

(1) total resistance.
(2) total current.
(3) total power.

c. Given a bridge circuit schematic diagram, make necessary calculations to determine whether the circuit is balanced or unbalanced.

## LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text KEP-ST-I
Programmed Text KEP-PT-8

AUDIO-VISUALS

TVK 30-101P Parallel Resistive Circuits (Analysis)
TVK 30-101Q Parallel Resistive Circuits (Power)
TVK 30-101R Resistive Bridge Circuits.

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

---

Supersedes KEP-GP-8, 1 February 1975. Use old edition until supply is exhausted.

## ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers in the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to Student Text Volume I and read paragraphs 5-61 thru 5-78. Return to this page and answer the following questions.

1. A parallel circuit is defined as

______________________________

______________________________

2. In a parallel circuit $E_a$, $E_1$, $E_2$, & $E_3$ are always

______________________________

______________________________

3. In a parallel circuit $I_t$ =

______________________________

4. The formula for finding $R_t$ for 3 resistors is

______________________________

5. The formula for finding $R_t$ for 2 unequal resistors is

______________________________

6. For parallel resistors of equal value use $R_t$ =

______________________________

7. When two 50-ohm resistors are connected in parallel, the equivalent resistance is:

______ a. 100 ohms.

______ b. 50 ohms.

______ c. 25 ohms.

______ d. 5 ohms.

8. When three resistors having values of 10, 20, and 30 ohms are connected in parallel, the equivalent resistance is:

______ a. More than 30 ohms.

______ b. Less than 10 ohms.

______ c. Less than 30 but more than 10 ohms.

______ d. 20 ohms.

CONFIRM YOUR ANSWERS

---

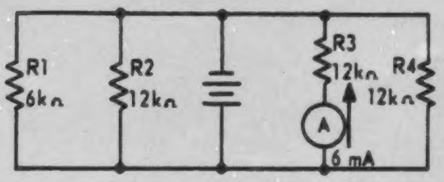
B. Turn to Student Text Volume I and read paragraphs 5-79 thru 5-101. Return to this page and answer the following questions.

1. What form of Ohm's Law would be used to solve for the applied voltage in a parallel circuit?

______ a. $E_a = \frac{I}{R}$ ______ b. $E_a = \frac{R}{I}$

______ c. $E_a = IR$ ______ d. $E_a = I + R$

2. In the diagram shown, if another resistor is placed in parallel with R4, what happens to total power?



REP4-850

______ a. Increases.

______ b. Decreases

______ c. Remains the same.

______ d. Depends on the applied voltage.

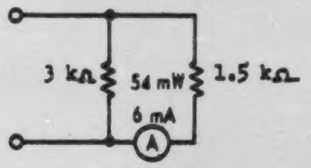
3. The applied voltage is:

_____ a. 324 volts.

_____ b. 110 volts.

_____ c. 55 volts.

_____ d. 9 volts.



REP4-851

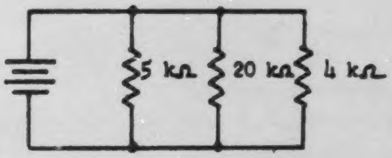
4. What is the total resistance?

_____ a. 29 k ohms

_____ b. 12 k ohms

_____ c. 4 k ohms

_____ d. 2 k ohms



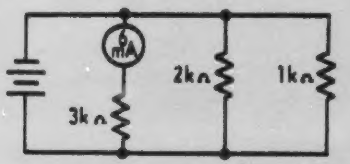
5. the total current is:

_____ a. 33 mA

_____ b. 36 mA

_____ c. 34 mA

_____ d. 22 mA



REP4-853

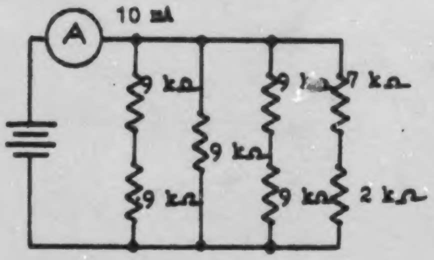
6. What is the applied voltage?

_____ a. 30 V

_____ b. 50 V

_____ c. 70 V

_____ d. 90 V



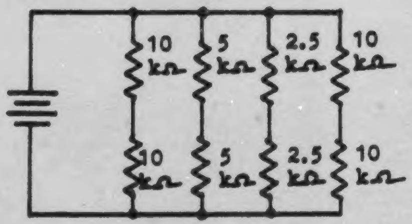
7. $R_t$ equals:

_____ a. 1.25 k ohms

_____ b. 2.5 k ohms

_____ c. 5 k ohms

_____ d. 10 k ohms



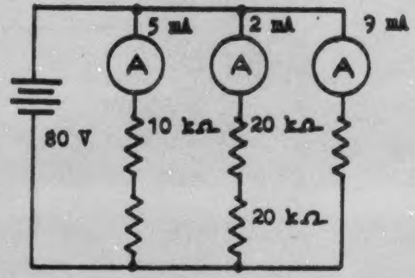
8. What is the total resistance?

_____ a. 5 k ohms

_____ b. 6 k ohms

_____ c. 8 k ohms

_____ d. 9 k ohms



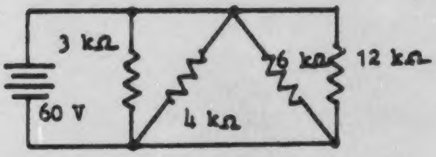
9. What is total current?

______ a. 20 mA

______ b. 30 mA

______ c. 40 mA

______ d. 50 mA



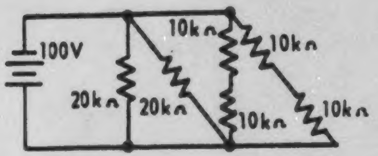
10. What is total power dissipated?

______ a. 5000 mW

______ b. 2000 mW

______ c. 500 mW

______ d. 20 mW



REP 4-859

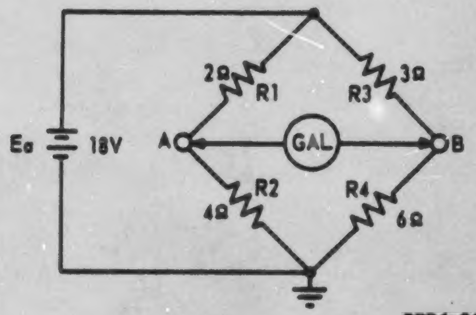
11. If another branch is added to a parallel circuit, $I_t$ will ______________________

and $R_t$ will ______________________.

CONFIRM YOUR ANSWERS

C. Turn to Student Text Volume I and read paragraphs 5-102 thru 5-114. Return to this page and answer the following questions.

1. Identify the conditions of the balanced bridge circuit.



REP4-937

______ a. Current flow through the galvanometer and no difference of potential between point A and B.

______ b. No current flow through the galvanometer and no difference of potential between points A and B.

______ c. No current flow through the galvanometer and a difference of potential between points A and B.

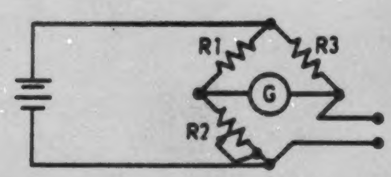
2. The bridge circuit shown may be used as a Wheatstone Bridge to measure

______ a. Current.

______ b. Voltage.

______ c. Resistance

______ d. Power.



REP 4-861

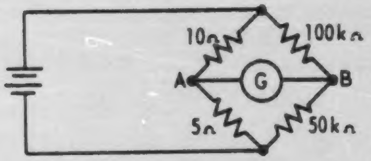
3. Decreasing $E_a$ will:

______ a. Increase current from A to B.

______ b. Increase current from B to A.

______ c. Decrease current from A to B.

______ d. Have no effect on current from A to B or B to A.



REP 4-862

4. If the voltage applied to a bridge circuit is increased, the current through the galvanometer will:

______ a. Increase, if the bridge is balanced.

______ b. Decrease, if the bridge is balanced.

______ c. Decrease, if the bridge is unbalanced.

______ d. Increase, if the bridge is unbalanced.

5. In order to use the bridge circuit to measure unknown resistances:

______ a. There must be no variable resistor.

______ b. One resistor must be variable.

______ c. Two resistors must be variable.

______ d. Three resistors must be variable.

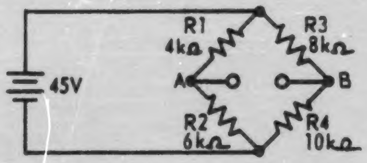
6. What is the voltage from A to B?

______ a. 25 V

______ b. 2 V

______ c. 27 V

______ d. 0 V

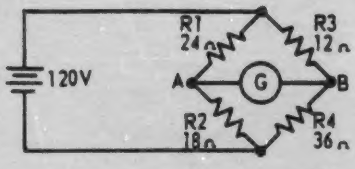


REP 4-863

7. Current flow will be from:

______ a. B to A.

______ b. A to B.



REP 4-864

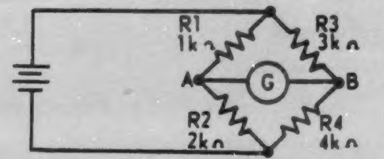
8. In the circuit shown, the current through the galvanometer is:

______ a. Zero.

______ b. Flowing from A to B.

______ c. Flowing from B to A.

______ d. Greater than $I_{R3}$.



REP 4-865

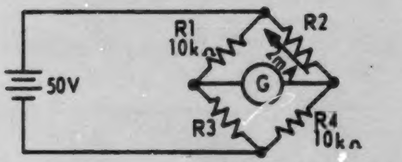
9. If the current through the galvanometer is zero, what is the resistance of R3?

______ a. 3.3 k ohms

______ b. 6.7 k ohms

______ c. 13.3 k ohms

______ d. 20 k ohms



REP 4-866

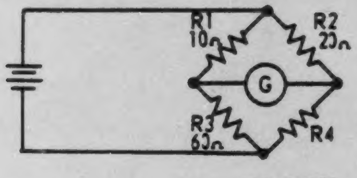
10. For the bridge to be balanced, the resistance of R4 must be:

______ a. 3.3 ohms.

______ b. 30 ohms.

______ c. 90 ohms.

______ d. 120 ohms.



REP 4-867

CONFIRM YOUR ANSWERS

______________________________

MODULE SELF-CHECK

QUESTIONS:

1. A parallel circuit is defined as

______________________________

______________________________

2. In a parallel circuit $E_a$, $E_1$, $E_2$ and $E_3$ are always

______________________________

3. In a parallel circuit $I_t$ =

______________________________

4. Kirchhoff's Law for current states that

______________________________

______________________________

______________________________

5. Kirchhoff's Law for voltage states that

______________________________

______________________________

______________________________

______________________________

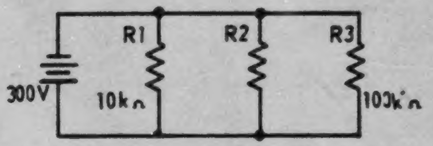
6. In the circuit shown,

a. total resistance = ______________

b. total current = ______________

c. total power = ______________

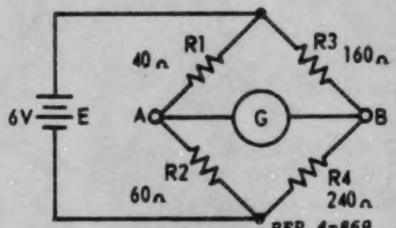
Remember E = IR & P = EI



REP 4-868

$I_{R2}$ = 12 mA

7. The bridge circuit shown is (balanced) (unbalanced).



REP 4-869

CONFIRM YOUR ANSWERS

______________________________

## ANSWERS TO A - ADJUNCT GUIDE

1. A circuit with two or more devices connected across the entire voltage source; a circuit having more than one path for current flow.
2. equal
3. $I_1 + I_2 + I_3$
4. $R_t = \dfrac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}}$
5. $R_t = \dfrac{R1 \times R2}{R1 + R2}$
6. $R_t = \dfrac{R}{N}$
7. c
8. b

If you missed ANY questions, review the material before you continue.

## ANSWERS TO B - ADJUNCT GUIDE

1. c
2. a
3. d
4. d
5. a
6. a
7. b
8. a
9. d
10. b
11. Increase-Decrease

If you missed ANY questions, review the material before you continue.

## ANSWERS TO C - ADJUNCT GUIDE

1. b
2. c
3. d
4. d
5. b
6. b
7. b
8. c
9. b
10. d

If you missed ANY questions, review the material before you continue.

## ANSWERS TO SELF-CHECK:

1. A circuit with two or more devices connected across the entire voltage source. A circuit with more than one path for current flow.
2. equal
3. $I_1 + I_2 + I_3$
4. The sum of all currents flowing to a point must be equal to the sum of all the currents flowing away from that point.
5. The applied voltage is equal to the sum of the voltage drops around the circuit.
6. a. 6.67 k ohms
   b. 45 mA
   c. 13.5 W
7. balanced

**HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.**

ATC PT 3AQR3X020-X
Prepared by Keesler TTC
KEP-PT-9

Technical Training

# Electronic Principles (Modular Self-Paced)

## Module 9

## SERIES-PARALLEL RESISTIVE CIRCUITS

November 1975

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

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Radar Principles Branch
Keesler Air Force Base, Mississippi

Programed Text KEP-PT-9
Prepared by Keesler TTC
November 1975

# Electronic Principles

## Module 9
## Series-Parallel Resistive Circuits

Most circuits in electronic equipment are combinations of series and parallel components. A series-parallel circuit consists of groups of parallel components connected in series with other components, and have both series and parallel paths for current flow. It is important that you as a technician know the operation of series-parallel circuits, know what is expected at various points in the circuit so that when malfunctions occur you will be able to isolate these malfunctions and correct them.

### OBJECTIVES

1. Given a series-parallel circuit schematic diagram and formulas, solve for total resistance, total current, total power, and individual voltage drops.

### INSTRUCTIONS

1. This programed text is presented in Frames. There are two frames on each page. Each frame should be completed in the following sequence:

   a. Complete only the top frame on page 1. Turn the page and check your answer.

   b. If your answer is not correct, return to the problem and find your error.

   c. Complete the top frame on page 3, and check your answers.

   d. Upon completion of the top frame of the last page, go back to page 1 at the front of the book and complete the bottom in sequential order front to back.

2. When you have completed the last frame, work the additional practice problem, if you feel that you need them. If not, complete the Module Self-Check.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP

Supercedes KEP-PT-9, 1 February 1975. Previous editions may be used.

# INSTRUCTIONS

1. This is a programed text and material is presented in frames. There are two frames on each page. You will complete each frame in the following sequence:

   a. Complete the top frame on page 1.

   b. Turn the page.

   c. Check your answer on the back of page 1 (Feedback).

   d. Complete the frame on page 2, etc.

   e. Upon completion of the top frame of the last page, go back to page 1 at the front of the book and complete the bottom in sequential order front to back.

2. Make sure each response is checked after each answer.

3. When you have completed the last frame, continue to the Test in back of the book.

4. Complete the Module Self-Check.

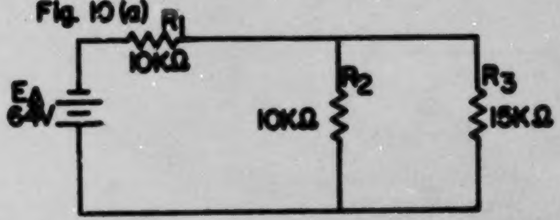
1. A circuit with both SERIES and PARALLEL paths for current flow is a Series Parallel Circuit.

When there are both Series and Parallel paths for current flow within a circuit that circuit is known as a S _ _ _ _ _ P _ _ _ _ _ _ _ circuit. (Answer on next page).

---

4.

Fig. 10 (a)



To solve for total current in the above circuit, we would use Ohm's Law $I_T = \frac{E_T}{R_T}$. We know the applied voltage is 64V and we have found that the total resistance is 16KΩ. All we need do now is substitute in the formula.

Solve for $I_T$. (Show Work)

$I_T$ = __________ Turn page for correct answer

1a.

## SERIES PARALLEL CIRCUIT

---

24a.

$$I = \frac{E}{R}$$

$$I_T = \frac{E_T}{R_T}$$

$$I_T = \frac{64V}{16K} = \frac{64 \times 10^0}{16 \times 10^3} = 4 \times 10^{-3} \text{ or } 4 \text{ ma}$$

2. Below are some schematic representations of Series-Parallel Circuits.

Fig. 1(a)

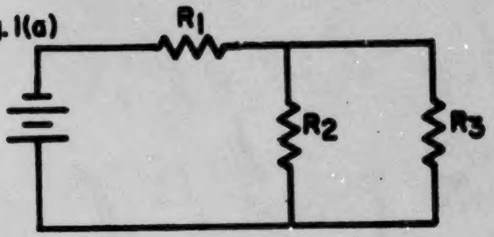


Fig. 3(a)

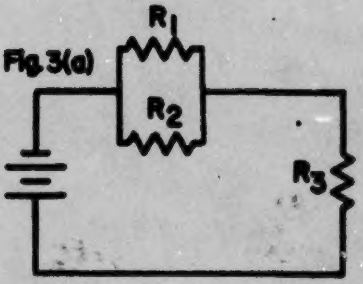


Fig. 2(a)

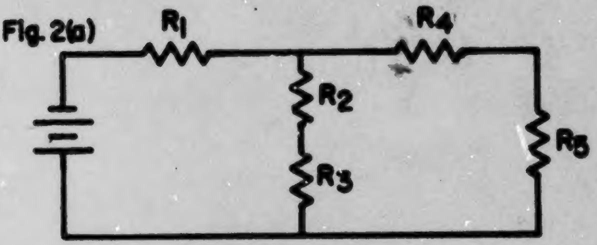


Figure 1 (a) is a schematic representation of a S______________ P______________ circuit

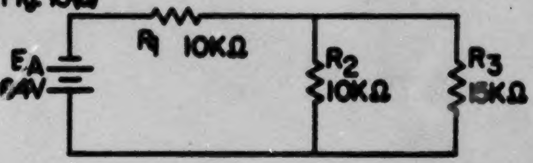
The circuit in 3 (a) is called a S______________ P______________ circuit.

Turn page for answer ⟶

---

25. According to the Series Circuit current rule, total current or 4 ma of current will flow through all components connected in series; therefore, 4 ma of current will flow through the ________ KΩ resistor since it is the series component.

Fig. 10(a)



Turn page for correct answer ⟶

2a.

SERIES PARALLEL CIRCUIT

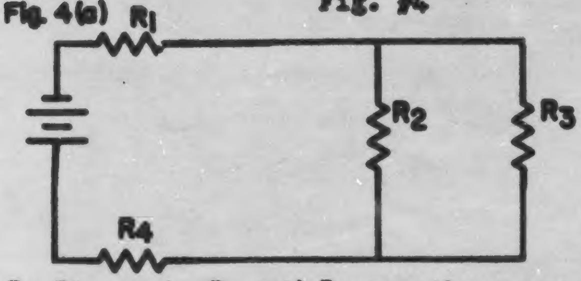
SERIES PARALLEL CIRCUIT

---

25a.

10K resistor

3. Fig. 4(a) Fig. #4.



In Figure 4, $R_1$ and $R_4$ are the components that are in series. $R_2$ and $R_3$ are in P__________. We call this circuit a __________ __________________ circuit.

Turn page for correct answer

---

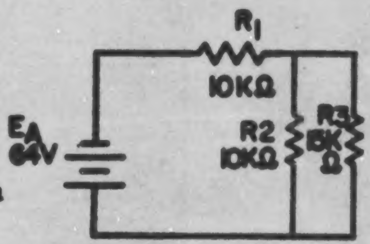
26. Now that we know the current through $R_1$ (total current) we may use Ohm's Law formula for finding the voltage drop across $R_1$.

$$E = I \times R \quad E_{R_1} = I_{R_1} \times R_1. \qquad E_{R_1} = 4 \text{ ma} \times 10K$$

$$E_{R_1} = (4 \times 10^{-3})(10 \times 10^{3}) = 40 \times 10^{0} \text{ or } 40V$$

We use only the values pertaining to the component that we are working with to solve for individual values. If we are solving for the voltage drop across $R_1$ we would use only the values that pertain to ____________.

Fig. #10a.



Turn page for correct answer

3a.

PARALLEL

SERIES PARALLEL

---

26a.

$R_1$

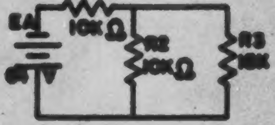
4. If both series and parallel paths for current flow is provided in a circuit we call that circuit a __________ __________ circuit.

Turn page for correct answer →

---

27. In a simple series-parallel circuit like the one that we are dealing with we may use Kirchhoff's voltage law to find the voltage drop across the parallel branch. "The sum of the voltage drops around any closed circuit equals the applied voltage."

Since the applied voltage in this circuit is 64V, and 40V was dropped across $R_1$ we can subtract 40V from the total voltage and thus find our voltage drop across $R_2$ and $R_3$.



$$R_T - R_1 = R_{2,3}$$

$$64V - 40V = 24V$$

Voltage dropped across the parallel branch is ________V.

In a parallel circuit the voltage is the same across each branch, therefore, if 24V is felt across $R_2$ we will also feel ________V across $R_3$.

4a.

SERIES PARALLEL

---

27a.

24V

24V

5. Draw two schematic representations of Series-Parallel Circuits.

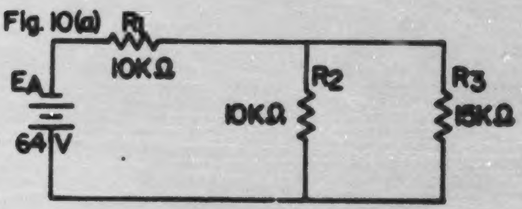
Turn page for correct answer

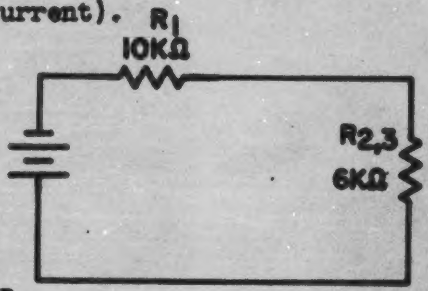
➡

---

26. We may also use the formula E = I X R to find the voltage drop across the parallel branch. This is our series equivalent of the circuit Fig. #10a. If 4 ma of total current flows in the circuit and the equivalent resistance of $R_{2\&3}$ is 6KΩ, we may use the formula E = I X R (using the equivalent resistance and total current).

Fig. 10(a)



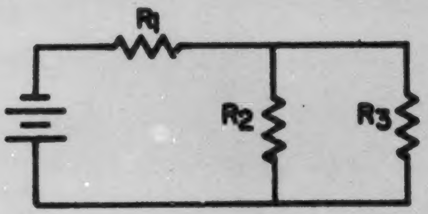


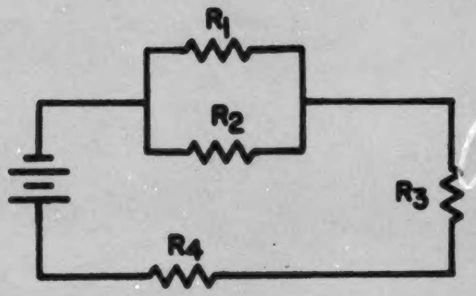
Solve for the voltage drop of $R_2$ and $R_3$.______
(Show work)

Turn page for correct answer

➡

5a.





The above circuits are two of the many possible schematic representations of series parallel circuits.

---

28a. $E = I \text{ X } R$

$E_{R_{2,3}} = I_{R_{2,3}} \text{ X } R_{2.3}$

$E_{R_{2,3}} = (4\text{ma})\ (6\text{K}\Omega)$

$E_{R_{2,3}} = (4 \text{ X } 10^{-3})\ (6 \text{ X } 10^{3})$

$E_{R_{2,3}} = 24 \text{ X } 10^{0}$

$E_{R_{2,3}} = 24\text{V}$

6. Series parallel circuits may look complicated but any circuit no matter how complex can be broken down into its Series Circuit equivalent. Below is an example of a complex looking Series-Parallel circuit and its series equivalent. Once the circuit is broken down into its _____ __________ it is very easy to find the resistance total of the circuit.

Fig.6(a)

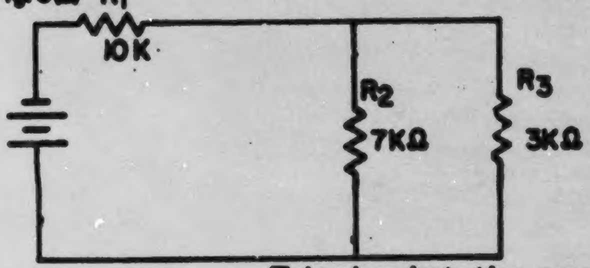


Fig.6(b)

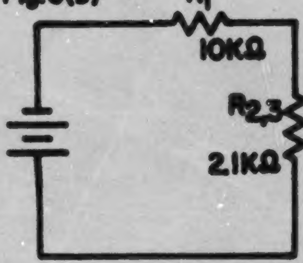
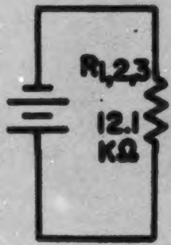


Fig.6(c)



This is what the power source actually sees →

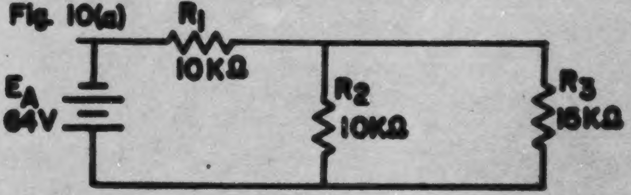
---

29. Now, we may again use Ohm's Law for calculating the current through $R_2$ and $R_3$, keeping in mind that in a parallel circuit "THE SUM OF THE BRANCH CURRENTS MUST EQUAL TOTAL CURRENT." To find current through $R_2$

$I = \frac{E}{R}$, $I_{R_2} = \frac{E_{R_2}}{R_2}$.

(Show Work)

Fig. 10(a)



__________ma current through $R_2$.

Turn page for correct answer →

6a.

SERIES EQUIVALENT

---

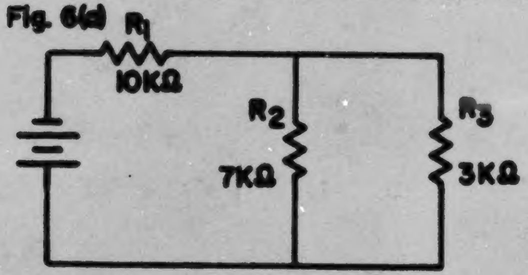
29a. $I = \frac{E}{R}$

$I_{R_2} = \frac{E_{R_2}}{R_2}$

$I_{R_2} = \frac{24V}{10K\Omega}$ $\qquad I_{R_2} = \frac{24 \times 10^0}{10 \times 10^3} = 2.4 \times 10^{-3}$ or 2.4 ma

699

Fig. 6a.



Let us study Fig. 6a. Since $R_1$ is in series, and $R_2$ and $R_3$ are the components that are in parallel, to solve for $R_T$, let us begin with $R_2$ and $R_3$ since they are farthest from the power source. These resistors are in parallel and are of unlike value; therefore, we will use the Product over the Sum method to solve for the equivalent resistance of the two branches.

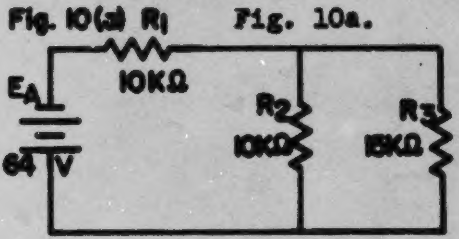
$R_T = \dfrac{R_1 \times R_2}{R_1 + R_2}$ is the formula for the P________ over the _____ method.

Turn page for correct answer →

---

30.

Fig. 10a.



If according to Kirchhoff's Law the sum of the individual branch currents must equal total current, and we have 4 ma of total current in the circuit, with 2.4 ma flowing through $R_2$ then we should have ______ ma flowing through $R_3$.

Turn page for correct answer →

7a.

PRODUCT OVER THE SUM METHOD

---

30a.

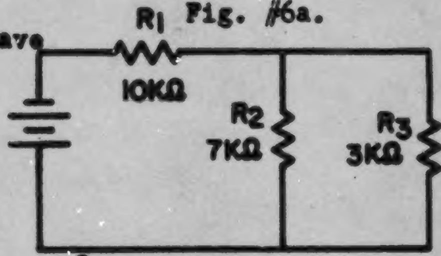
4.0 ma of total

-2.4 ma through $R_2$

1.6 through $R_3$

8. Substituting in our formula using the product over the sum method we have

Fig. #6a.

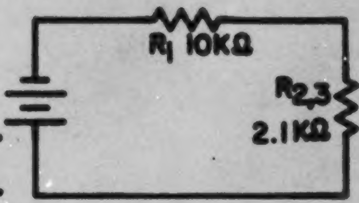


$$R_T = \frac{R_2 \times R_3}{R_2 + R_3} \qquad R_T = \frac{7K \times 3K}{7K + 3K}$$

Converting to powers of ten we have

$$\frac{(7 \times 10^3)\ (3 \times 10^3)}{(7 \times 10^3) + (3 \times 10^3)} = \frac{21 \times 10^6}{10 \times 10^3} = 2.1 \times 10^3 \text{ or } 2.1K\Omega$$

Fig. #6b.



Our circuit now looks like Figure 6b.

To find the equivalent resistance of the two components of unlike value in Fig. 6a. we used the ______ over the ______ method.

Turn page for Correct Answer

---

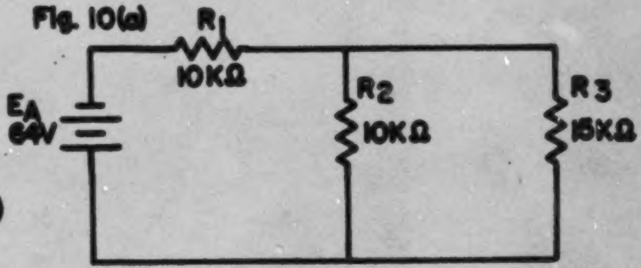
31. We may also solve for $I_{R_3}$ by using Ohm's Law and the values that pertain to $R_3$.

$$I = \frac{E}{R}.$$

$$I_{R_3} = \frac{E_{R_3}}{R_3}$$

Solve for $I_{R_3}$ (Show work)

Fig. 10(a)



Turn page for correct answer

702

8a.

Product over the Sum Method

---

31a. $I = \frac{E}{R}$

$$I_{R_3} = \frac{E_{R_3}}{R_3}$$

$$I_{R_3} = \frac{24V}{15K} = I_{R_3} = \frac{24 \times 10^0}{15 \times 10^3} = 1.6 \times 10^{-3} \text{ or } 1.6 \text{ ma}$$

$I_{R_3}$ = 1.6 ma of current.

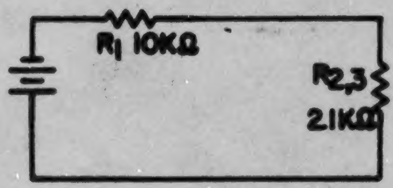
9. Our series circuit resistance formula may now be used.

$R_T = R_1 + R_2 + R_3$. Substituting $R_T = R_1 + R_{2,3}$

$R_T = 10K\Omega + 2.1K\Omega$ $R_T = 12.1K\Omega$

We have broken the circuit in Figure 6a. down into its

Series equivalent.



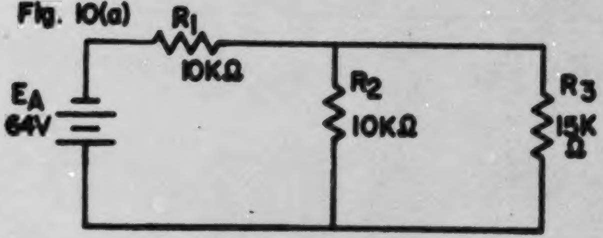
Any circuit no matter how complex can be broken down into its ________ equivalent in order to find $R_T$.

Turn page for correct answer →

---

32. NOTE: We have now solved for all the missing values in this circuit. Fill in the missing values.

Fig. 10(a)



$R_T$ ____________

$I_T$ ____________

$I_{R_1}$ ____________

$E_{R_1}$ ____________

$I_{R_2}$ ____________

$E_{R_2}$ ____________

$I_{R_3}$ ____________

$E_{R_3}$ ____________

Turn page for correct answer →

9a.

## SERIES EQUIVALENT

---

32a. $R_T$ 15KΩ

$I_T$ 4 ma

$I_{R_1}$ 4 ma

$E_{R_1}$ 40 V

$I_{R_2}$ 2.4 ma

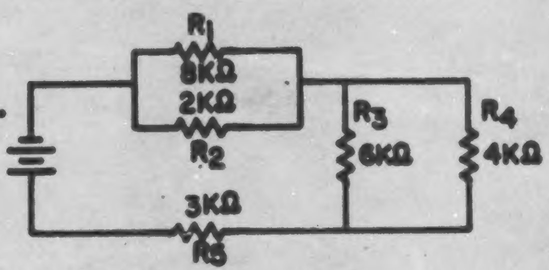
$E_{R_2}$ 24 V

$I_{R_3}$ 1.6 ma

$E_{R_3}$ 24 V

10.

Fig. #7a.



When there are two resistors of unlike value in a circuit, we use the Product Over the Sum Method to find the equivalent resistance of that branch.

To find the equivalent resistance of $R_1 + R_2$ in Figure 7a, we would use the P___________ over the S____ method.

(a) The equivalent resistance of $R_1 + R_2$ is ______K.

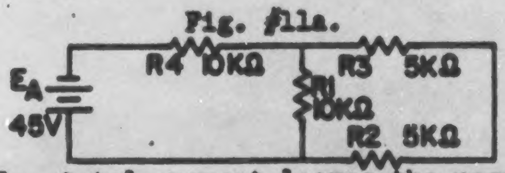
NOTE: If you did not do this correctly turn back and review what you have read.

←

---

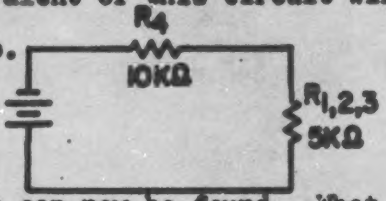
33.

Fig. #11a.



In Figure 11a. total current leaves the negative side of the power source, a portion goes through $R_1$, the remainder goes through $R_2$ and $R_3$, combines, and total current goes through $R_4$ before returning to the positive side of the power source. Our series equivalent of this circuit will look like this.

Fig. 11b.



Total resistance of the circuit can now be found. What is the $R_t$ of the circuit?

____________K.

Turn page for correct answer →

10a. Product over the sum.

(a) $R_T = \frac{R_1 \text{ X } R_2}{R_1 + R_2} = \frac{8K \text{ X } 2K\Omega}{8K + 2K\Omega}$ $\frac{(8 \text{ X } 10^3)\ (2 \text{ X } 10^3)}{8 \text{ X } 10^3 + 2 \text{ X } 10^3} =$

$\frac{16 \text{ X } 10^6}{10 \text{ X } 10^3} = 1.6 \text{ X } 10^3$ or 1.6KΩ

---

33a. $R_4$ is the series component.

$R_1$ is in parallel to $R_{2,3}$ which are in series

therefore $R_{2,3}$ are additive

$5K + 5K = 5 \text{ X } 10^3 + 5 \text{ X } 10^3 = 10 \text{ X } 10^3$

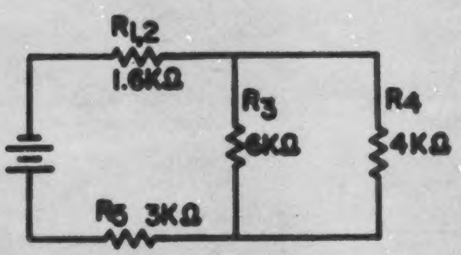
$R_1 = 10K$

$R_{1,2,3} = \frac{R}{N} = \frac{10K}{2} = 5K$

$R_T = R_{1,2.3} + R_4 = 5K + 10K = 5 \text{ X } 10^3 + 10 \text{ X } 10^3 = 15K$

$R_T = 15K\Omega$

11. Fig. #7b



$R_3$ and $R_4$ are also in parallel and are of unlike value: therefore, we would still use the PRODUCT over the SUM method to solve for the equivalent resistance of these two branches. Using this method, we find the equivalent resistance of the parallel branch to be ______KΩ. (Show Work)

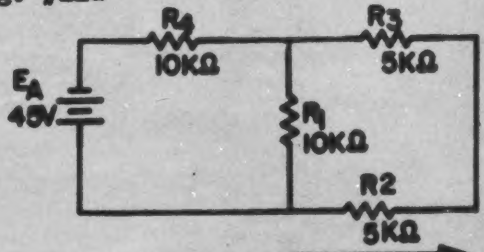
(Turn page for computations) ➡

---

34. The circuit in Fig. #11a. is more complicated than the others we have studied. Please keep in mind that the values to be found do not have to be solved for in the order they are listed. It would be easier to find the current and the voltage drop of the series components first. What is the $I_T$ of the circuit? (Show Work)

$I_T$ ________

Fig. #11a



Turn page for correct answer ➡

11a.

$$R_T = \frac{R_3 \times R_4}{R_3 + R_4} = \frac{6K \quad \times 4K}{6K \quad + 4K} = \frac{(6 \times 10^3) \quad (4 \times 10^3)}{(6 \times 10^3) + (4 \times 10^3)} = \frac{24 \times 10^6}{10 \times 10^3} =$$

$2.4 \times 10^3$ or $2.4\ K\Omega$

---

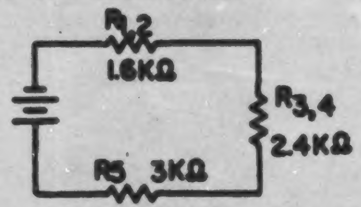
34a. $E_A = 45V$

$R_T = 15K\Omega$

$$I_T = \frac{E_T}{R_T} = \frac{45V}{15K} = \frac{45 \times 10^0}{15 \times 10^3} = 3 \times 10^{-3} = 3 \text{ ma}$$

12. After finding our equivalent resistance of $R_3 + R_4$ we should now have a circuit that looks like this.

Fig. #7c.



We can now employ our Series Circuit resistance rule to the circuit and add the resistances.

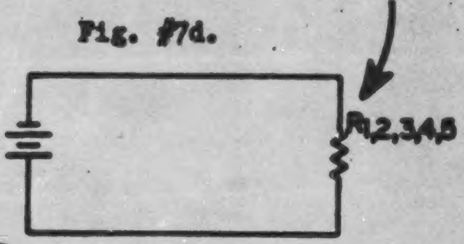
$R_T = R_1 + R_2 + R_3 + R_4$

$R_T = 1.6K + 2.4K + 3K$

$R_T =$ ______________ KΩ

This is what the power source sees.

Fig. #7d.



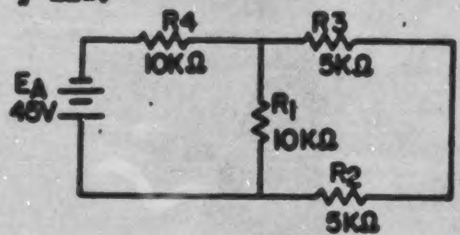
Turn page for correct answer →

---

35. Now that we have a total resistance and total current, we know the amount of current that flows through $R_4$ since it is our series component. It is easier now to solve for $E_{R_4}$ using the formula $E = I \times R$. $E_{R_4} = I_{R_4} \times R_4$

Fig. # 11a.

$E_{R_4} =$ ________ V.



Turn page for correct answer →

12a.

7KΩ

---

35a. $E = I \times R$

$E_{R_4} = I_{R_4} \times R_4$

$E_{R_4} = 3 \text{ ma} \times 10K\Omega$

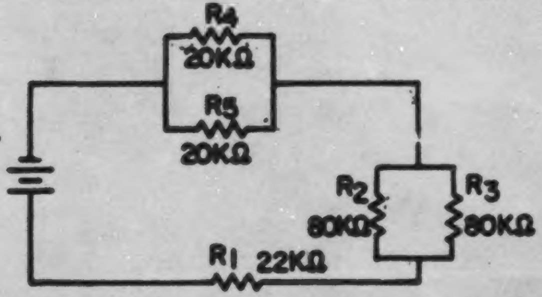
$E_{R_4} = (3 \times 10^{-3})\ (10 \times 10^{3})$

$E_{R_4} = 30 \times 10^{0}$

$E_{R_4} = 30 \text{ V}$

13.

Fig. #8a.



In Fig. #8a. $R_1$ is the series resistor. $R_2$, $R_3$ also $R_4$, $R_5$ are of like value; therefore, we will use the Like Method to solve for the equivalent resistance of these branches. The formula $R_t = \frac{R}{N}$. For $R_{2,3}$ we say $R_t = \frac{R}{N}$ $R_t = \frac{80K\Omega}{2}$

$R_t = 40K\Omega$ is the equivalent resistance of $R_{2,3}$.

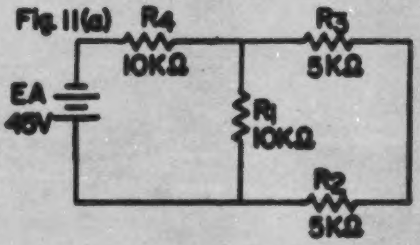
Using the L _ _ _ M _ _ _ _ _ _ we find the equivalent resistance of $R_{4,5}$ to be _______KΩ (Show Work)

Turn page for Correct Answer →

---

36. Since $R_1$ is in parallel with $R_2$ and $R_3$ which are in series, we know that according to our parallel circuit voltage rule, $R_1$ will feel the difference between total voltage and the voltage dropped across $R_4$, and that $E_{R_2}$ and $E_{R_3}$ voltage will add up to equal that same voltage since they are in series, but are parallel to $R_1$.

Fig. 11(a)



$E_{R_1}$ = 45V - 30V or _____V. What is the voltage drop across $R_1$

$E_{R_1}$ = _______V.

Turn page for Correct Answer →

13a.

LIKE METHOD

(a) 10KΩ  $R_T = \frac{R}{N}$  $R_T = \frac{20K}{2}$  $R_T = 10K\Omega$

---

36a.

$$E_{R_1} = E_T - E_{R_4}$$
$$= 45V - 30V$$
$$= 15V$$

$E_{R_1} = 15V$

14. If your answer was 10 KΩ of equivalent resistance for $R_4$ and $R_5$ you were correct.

NOTE: If you failed to get 10 KΩ you have forgotten the Like Method. Let us review quickly. If all the components are of like value, we can use the like method $R_T = \frac{R}{N}$. R stands for the value of either of the resistors since they are all alike, N stands for the actual number of resistors that are of like value. If we had 4 - 12 K resistors we would use the formula $R_T = \frac{R}{N}$. $R_T = \frac{12}{4}$

The total effective resistance of the circuit would be

__________ kΩ.

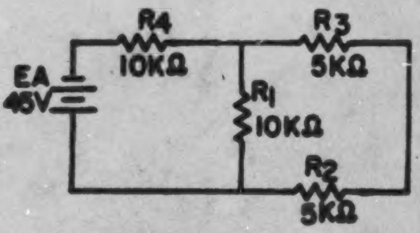
Turn page for Correct Answer →

---

37. Now that we know the voltage drop of $R_1$, we can use Ohm's Law to solve for the current through $R_1$ by using the formula $I_{R_1} = \frac{E_{R_1}}{R_1}$

Solve for the current through $R_1$

Fig. #11a



Turn page for Correct Answer →

14a.

3KΩ

---

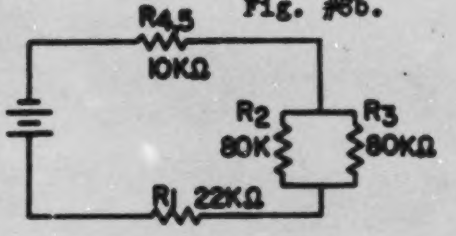
37a. $I_{R_1} = \frac{E_{R_1}}{R_1}$

$I_{R_1} = \frac{15V}{10K\Omega} = \frac{15 \times 10^0}{10 \times 10^3} = 1.5 \times 10^{-3}$

$I_{R_1} = 1.5$ ma

15. Let us go back to Figure 8a. After finding the equivalent resistance of $R_4$ and $R_5$ to be 10KΩ , our circuit now looks like this:

Fig. #8b.



To find the equivalent resistance of $R_2$ and $R_3$ we now would use the L _ _ _ M _ _ _ _ _.

Turn page for Correct Answer →

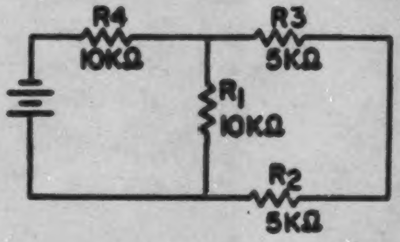
---

38. Since we have found the current through $R_1$ and we know that the balance of the total current will flow through $R_2$ and $R_3$ because they are in series yet are parallel to $R_1$, we merely subtract $R_1$ current from total current: thus giving us current for $R_2$ and $R_3$.

Solve for $I_{R_2}$ ________

$I_{R_3}$ ________

Fig. #1a.



Turn page for Correct Answer →

15a.

LIKE METHOD

---

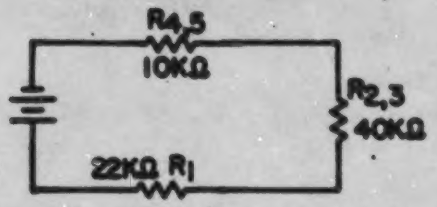
38a. $I_{R_{2,3}}$ (Series Components)

$$I_{R_{2.3}} = I_T - I_{R_1} = 3 \text{ ma} - 1.5 \text{ ma}$$
$$= 1.5 \text{ ma}$$

16. $R_2$ and $R_3$ are also of like value and they are also in parallel. We use the L_ _ _ M _ _ _ _ _ _ to solve for the equivalent resistance of these two branches. Since we used the ________________ to solve for the equivalent resistance of $R_2$ and $R_3$ we found our equivalent resistance to be ______________ KΩ . (Show Work)

Now we have a circuit that looks like this:

Fig. #6c.



Turn page for Correct Answer →

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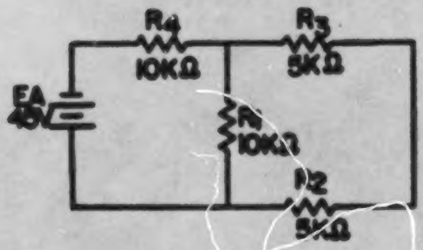
39. Now that we have solved for the current through $R_2$ and $R_3$, we may use Ohm's Law to calculate for $E_{R_2}$ and $E_{R_3}$ by applying the formula E = I X R

Solve for $E_{R_2}$ ______________ (Show Work)

Fig. # 11a.



Turn page for Correct Answer →

7/8

16a.

Like Method

Like Method $R_T = \frac{R}{N}$

40KΩ $R_T = \frac{80\ K}{2}$

$R_T = 40\ K\Omega$

---

39a. $E = I \times R$

$E_{R_2} = I_{R_2} \times R_2$

$E_{R_2} = 1.5\ \text{ma} \times 5K$

$E_{R_2} = (1.5 \times 10^{-3})\ (5 \times 10^{3})$

$E_{R_2} = 7.5 \times 10^{0}$

$E_{R_2} = 7.5\ V$

17. Now that the circuit has been reduced to its series equivalent, we may now employ our series resistance rule to solve for total resistance.

$R_T = R_1 + R_2 + R_3$   $R_T = 22K + 40K + 10K$

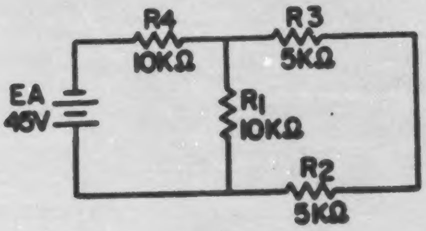
$R_T =$ ____________KΩ

Turn page for Correct Answer →

---

40. Solve for $E_{R_3}$________. (Show Work)

Fig.#11a.



Turn page for Correct Answer →

17a.

72KΩ

---

40a. $E = I \times R$

$E_{R_3} = I_{R_3} \times R_3$

$E_{R_3} = 1.5 \text{ ma} \times 5K$

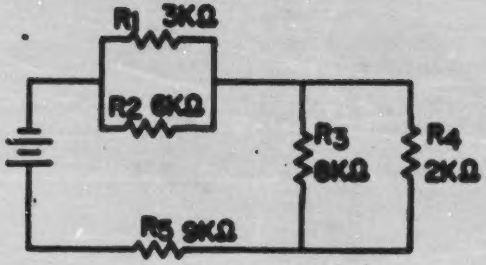
$E_{R_3} = (1.5 \times 10^{-3})\ (5 \times 10^{3})$

$E_{R_3} = 7.5 \times 10^{0}$

$E_{R_3} = 7.5V$

18. Calculate the total resistance of the circuit below:

Fig. #9a.



$R_T$ = ____________ KΩ

Turn page for Correct Answer →

---

41. We have now solved for all of the missing values in the circuit of Fig. #11a. We have used Ohm's and Kirchhoff's Laws to do this. Now fill in the missing values in the circuit below:

$E_A$ ____________

$R_T$ ____________

$I_T$ ____________

$I_{R_1}$ ____________

$E_{R_1}$ ____________

$I_{R_2}$ ____________

$E_{R_2}$ ____________

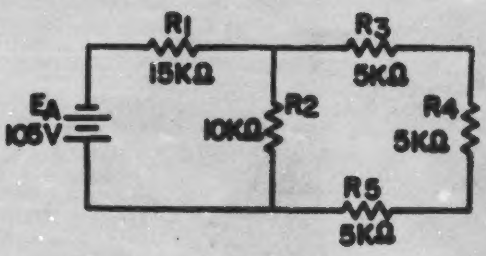
$I_{R_3}$ ____________

$E_{R_3}$ ____________

$I_{R_4}$ ____________

$E_{R_4}$ ____________

Fig. #11a.



Turn page for Correct Answer →

18a. $R_T = \frac{R_3 \times R_4}{R_3 + R_4} = \frac{8K \times 2K}{8K + 2K} = \frac{(8X10^3)\ (2X10^3)}{(8X10^3)+(2X10^3)} = \frac{16X10^6}{10X10^3} = 1.6X10^3$

or 1.6KΩ

$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{3K \times 6K}{3K + 6K} = \frac{(3X10^3)\ (6X10^3)}{(3X10^3)+(6X10^3)} = \frac{18X10^6}{9X10^3} = 2X10^3$ or 2KΩ

$R_5 = 9K\Omega$

$R_T = R_1 + R_2 + R_3$

$R_T = R_{1,2} + E_{3,4} + R_5$

$R_T = 2K + 1.6K + 9K$

$R_T = 12.6K\Omega$

---

41a. $E_A$ 105V

$R_T$ 21KΩ

$I_T$ 5 ma

$I_{R_1}$ 5 ma

$E_{R_1}$ 75V

$I_{R_2}$ 3 ma

$E_{R_2}$ 30V

$I_{R_3}$ 2 ma

$E_{R_3}$ 10V

$I_{R_4}$ 2 ma

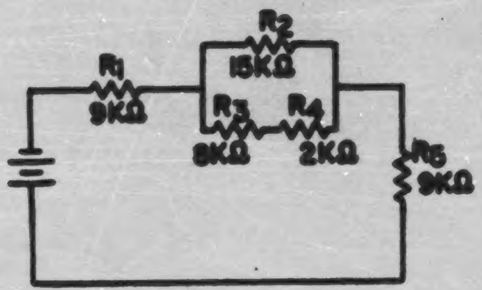
$E_{R_4}$ 10V

$I_{R_5}$ 2 ma

$E_{R_5}$ 10V

19. Calculate the total resistance of the circuit below:

Fig. #9b.



$R_T$ = __________KΩ

Turn page for Actual Computations →

---

42. Total power dissipation in a series-parallel circuit is found by adding the power dissipated by each resistor. The formula to use is $P_T = P_{R_1} + P_{R_2} + P_{R_3} + P_{R_N}$

The formula for finding total power dissipation in a series-parallel circuit is $P_T$ = ____________.

Turn page for correct answer →

19a. $R_1 = 9K$

$R_5 = 9K$

$R_3 + R_4 = 10K$

$$R_T = \frac{R_3R_4 \times R_2}{R_3+R_4+R_2} = \frac{10K \times 15\ K}{10K + 15K} = \frac{150 \times 10^6}{25 \times 10^3} = 6K$$

$R_T = R_1 + R_{2,3,4} + R_5$

$R_T = 9K + 6K + 9K$

$R_T = 24K\Omega$

---

42a. $P_T = P_{R_1} + P_{R_2} + P_{R_3} + P_{R_H}$

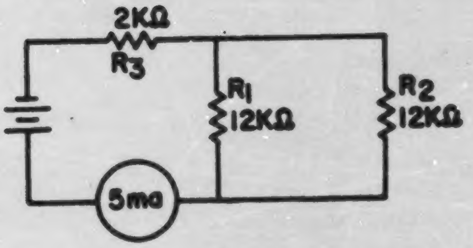
20. Current and voltage in a Series-parallel circuit may be found by using Ohm's Law along with Kirchhoff's voltage and current Laws. The first value to solve for in any circuit is TOTAL RESISTANCE.

When solving for unknown values in a circuit, the first value to solve for is T ____ R ________.

---

43. Example:

Fig. #12a.



If $P_{R_1}$ dissipates 75 mw of power and $P_{R_2}$ dissipates 75 mw of power and $P_{R_3}$ dissipates 50 mw of power, we can find total power dissapation by adding

$P_{R_1}$ = 75mw
$P_{R_2}$ = 75mw
$P_{R_3}$ = 50mw

$P_T$ = _________mw

Turn page for correct answer →

20a.

TOTAL RESISTANCE

---

43a.

200 mw

21. Once total resistance in a circuit is found, we may then find TOTAL Current if total voltage is given, using Ohm's Law.

$I = \frac{E}{R}$ $\qquad$ $I_T = \frac{E_T}{R_T}$

If total voltage is given in a circuit and we have found total resistance, we can find T _ _ _ _ C _ _ _ _ _ _ using O _ _ _ Law.

---

44. To solve for individual power dissipation in a series-parallel circuit we use one of the three power formulas that we were previously taught. We use $P = I \times E$ if current and voltage are given. We use $P = I^2R$ if current and resistance are given, and we use $P = \frac{E^2}{R}$ if voltage voltage and resistance are given. If we have voltage, current and resistance given, we may use EITHER of the three power formulas.

When voltage current and resistance are given in a series-parallel circuit, we may use (one of, either of, none of) the three power formulas. (Choose correct answer) ⟶

21a.

TOTAL CURRENT

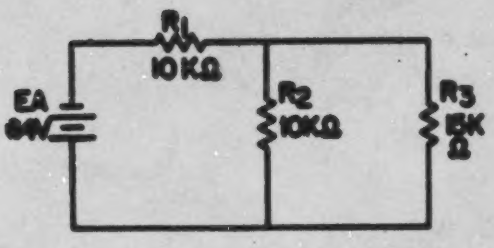
OHM's LAW

---

44a.

EITHER

22. Fig. #10a.

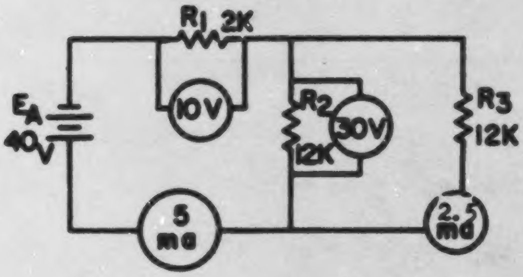


To solve for all unknown values in the above circuit, we would first solve for $R_T$. (Resistance total)

Solve for $R_T$ (Show work)

---

45. Fig. #13a.



In the following circuit we are given enough known values to solve for $P_{R_1}$, $P_{R_2}$, $P_{R_3}$ and $P_T$. (Show Work)

Solve for

$P_{R_1}$ ____________

$P_{R_2}$ ____________

$P_{R_3}$ ____________

$P_T$ ____________

Turn page for correct answer →

22a. $R_{2,3} = \dfrac{R_2 \text{ X } R_3}{R_2 + R_3}$

$R_{2,3} = \dfrac{10K\Omega \text{ X } 15K\Omega}{10K + 15K} = \dfrac{(10 \text{ X } 10^3)\ (15 \text{ X } 10^3)}{(10 \text{ X } 10^3)+(15 \text{ X } 10^3)} = \dfrac{150 \text{ X } 10^6}{25 \text{ X } 10^3} =$

$6 \text{ X } 10^3$ or $6K\Omega$

$R_T = R_1 + R_{2,3} = 10K\Omega + 6K\Omega = 10 \text{ X } 10^3 + 6 \text{ X } 10^3 = 16 \text{ X } 10^3$

or $16K\Omega$

---

45a. $P = I \text{ X } E$

$P_{R_1} = I_{R_1} \text{ X } E_{R_1}$

$P_{R_1} = 5$ ma X 10V

$P_{R_1} = (5 \text{ X } 10^{-3})(10 \text{X} 10^0)$

$P_{R_1} = 50 \text{ X } 10^{-3}$

$P_{R_1} = 50$ mw

$P = I \text{ X } E$

$P_{R_2} = I_{R_2} \text{ X } E_{R_2}$

$P_{R_2} = 2.5$ ma X 30V

$P_{R_2} = (2.5 \text{ X } 10^{-3})(30 \text{ X } 10^0)$

$P_{R_2} = 75 \text{ X } 10^{-3}$

$P_{R_2} = 75$ mw

$P = I \text{ X } E$

$P_{R_3} = I_{R_3} \text{ X } E_{R_3}$

$P_{R_3} = 2.5$ma X 30V

$P_{R_3} = (2.5 \text{ X } 10^{-3})(30 \text{X} 10^0)$

$P_{R_3} = 75 \text{ X } 10\text{-}3$

$P_{R_3} = 75$ mw

$P_T = P_{R_1} + P_{R_2} + P_{R_3}$

$P_{R_1} = 50$ mw

$P_{R_2} = 75$ mw

$P_{R_3} = 75$ mw

$P_T = 200$ mw

23. Applied voltage is given in the circuit as 64V. We found equivalent resistance to be 16KΩ. We may now use Ohm's Law and solve for total current. Ohm's Law current formula is $I = \frac{E}{R}$, for total current we say

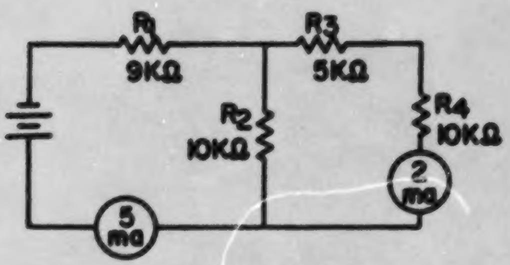
$$I_T = \frac{E_T}{R_T}$$

To find total current in a circuit we use Ohm's Law formula $I_T$ = ________.

---

46. In the following circuit solve for the following power dissipations:

Fig. #14a.



$P_{R_1}$ ______
$P_{R_2}$ ______
$P_{R_3}$ ______
$P_{R_4}$ ______
$P_T$ ______

Turn page for Correct Answer →

23a. $I_T = \dfrac{E_T}{R_T}$

---

46a. $P = I^2R$

$P_{R_1} = I^2_{R_1} \times R_1$

$P_{R_1} = (5ma)^2\ (9K\Omega)$

$P_{R_1} = (5 \times 10^{-3})^2\ (9 \times 10^3)$

$P_{R_1} = (25 \times 10^{-6})(9 \times 10^3)$

$P_{R_1} = 225 \times 10^{-3}$

$P_{R_1} = 225$ mw

$P = I^2R$

$P_{R_2} = I^2_{R_2} \times R_2$

$P_{R_2} = (3ma)^2\ (10\ K\Omega)$

$P_{R_2} = (3 \times 10^{-3})^2(10 \times 10^3)$

$P_{R_2} = (9 \times 10^{-6})\ (10 \times 10^3)$

$P_{R_2} = 90 \times 10^{-3}$

$P_{R_2} = 90$ mw

$P = I^2R$

$P_{R_3} = I^2\ R_3$

$P_{R_3} = (2ma)^2(5\ K\Omega)$

$P_{R_3} = (\ 2 \times 10^{-3})^2(5 \times 10^3)$

$P_{R_3} = (4 \times 10^{-6})(5 \times 10^3)$

$P_{R_3} = 20 \times 10^{-3}$

$P_{R_3} = 20$ mw

$P = I^2R$

$P_{R_4} = I^2_{R_4} \times R_4$

$P_{R_4} = (2\ ma)^2\ (10K\Omega)$

$P_{R_4} = (4 \times 10^{-6})\ 10 \times 10^3)$

$P_{R_4} = 40 \times 10^{-3}$

$P_{R_4} = 40$ mw

$P_T = P_{R_1} + P_{R_2} + P_{R_3} + P_{R_4}$

$P_{R_1} = 225$ mw

$P_{R_2} = 90$mw

$P_{R_3} = 20$mw

$P_{R_4} = 40$ mw

$P_T = 375$ mw

NOTE: Turn back to Page 1 and continue working

---

47. In the circuit below, solve for power dissipation using the appropriate formula. (Show Work)

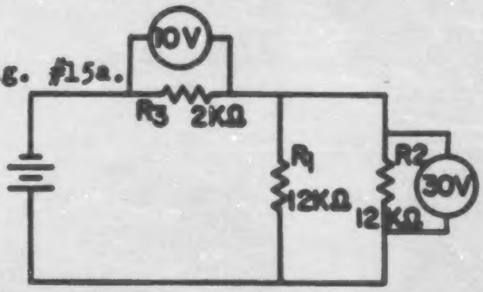
$P_{R_1}$ ______

$P_{R_2}$ ______

$P_{R_3}$ ______

$P_T$ ______

Fig. #15a.



NOTE: If you finish this part of the text before the allotted time, do the additional practice work that begins on the next page.

Turn page for correct answer

47a. $P = \frac{E^2}{R}$

$P_{R_1} = E_{R_1}^2$

$P_{R_1} = \frac{(30V)^2}{12K}$

$P_{R_1} = \frac{900 \text{ X } 10^0}{12 \text{ X } 10^3}$

$P_{R_1} = 75 \text{ X } 10^{-3}$

$P_{R_1} = 75mw$

$P = \frac{E^2}{R}$

$P_{R_2} = \frac{E_{R_2}^2}{R_2}$

$P_{R_2} = \frac{(30V)^2}{12K}$

$P_{R_2} = \frac{900 \text{ X } 10^0}{12 \text{ X } 10^3}$

$P_{R_2} = 75 \text{ X } 10^{-3}$

$P_{R_2} = 75mw$

$P = \frac{E^2}{R}$

$P_{R_3} = \frac{E_{R_3}^2}{R_3}$

$P_{R_3} = \frac{(10V)^2}{2K}$

$P_{R_3} = \frac{100 \text{ X } 10^0}{2 \text{ X } 10^3}$

$P_{R_3} = 50 \text{ X } 10^{-3}$

$P_{R_3} = 50 \text{ mw}$

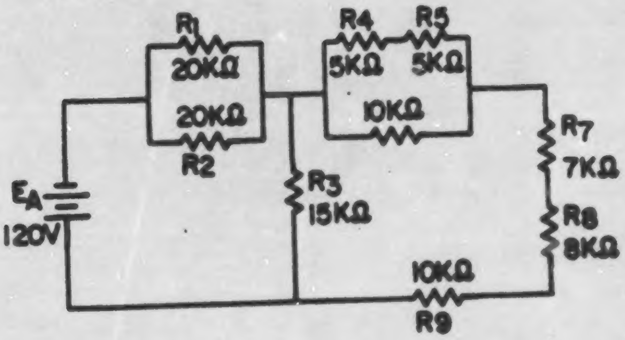
$P_{R_1} = 75mw$
$P_{R_2} = 75 \text{ mw}$
$P_{R_3} = 50mw$

$P_T = 200mw$

---

Additional Practice Work

Fig. #16a.



Solve for:

$R_T$ ________

$I_T$ ________

$I_{R_1}$ ________

$E_{R_1}$ ________

$I_{R_2}$ ________

$E_{R_2}$ ________

$I_{R_3}$ ________

$E_{R_3}$ ________

$I_{R_4}$ ________

$I_{R_5}$ ________

$I_{R_6}$ ________

$E_{R_4}$ ________

$E_{R_5}$ ________

$E_{R_6}$ ________

$I_{R_7}$ ________

$I_{R_8}$ ________

$I_{R_9}$ ________

$E_{R_7}$ ________

$E_{R_8}$ ________

$E_{R_9}$ ________

Turn page for correct answers →

**SERIES - PARALLEL DC CIRCUITS BX-[illegible]**

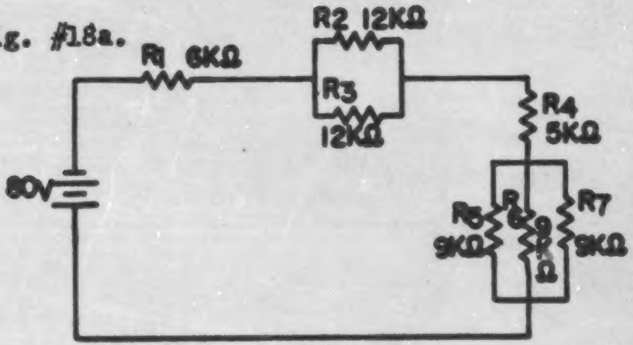
$R_T$ = 20K
$I_T$ = 6ma
$I_{R_1}$ = 3 ma
$E_{R_1}$ = 60V
$I_{R_2}$ = 3ma
$E_{R_2}$ = 60V
$I_{R_3}$ = 4 ma
$E_{R_3}$ = 60V
$E_{R_4}$ = 5V

$E_{R_5}$ = 5V
$E_{R_6}$ = 10V
$I_{R_4}$ = 1ma
$I_{R_5}$ = 1ma
$I_{R_6}$ = 1ma
$I_{R_7}$ = 2ma
$E_{R_7}$ = 14V
$I_{R_8}$ = 2ma

$E_{R_8}$ = 16V
$E_{R_9}$ = 20V
$I_{R_9}$ = 2ma

## Additional Practice Work

Fig. #18a.



Solve for the power dissipations in the above circuit:

$P_{R_1}$ ________

$P_{R_2}$ ________

$P_{R_3}$ ________

$P_{R_4}$ ________

$P_{R_5}$ ________

$P_{R_6}$ ________

$P_{R_7}$ ________

$P_T$ ________

Turn page for correct answers →

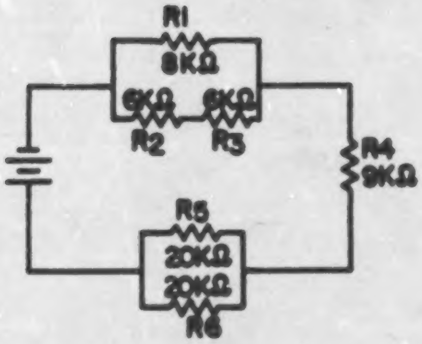
$P_{R_1}$ = 96mw
$P_{R_2}$ = 48mw
$P_{R_3}$ = 48mw
$P_{R_4}$ = 80mw
$P_{R_5}$ = 16mw
$P_{R_6}$ = 16mw
$P_{R_7}$ = 16mw
$P_T$ = 320mw

## Module Self-Check

1. Draw a schematic representation of a series parallel D.C. circuit using the following circuit values.

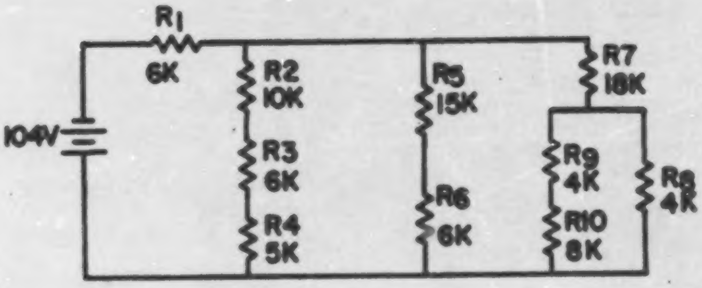
   $E_A$ = 144V
   $R_1$ = 9KΩ
   $R_2$ = 8KΩ
   $R_3$ = 15KΩ
   $R_4$ = 10KΩ
   $R_5$ = 12KΩ
   $R_6$ = 3KΩ

2. Solve for total resistance in the following circuit:



## Module Self-Check

3.



Solve for:

$R_T$ ________

$I_T$ ________

$I_{R_1}$ ________

$E_{R_1}$ ________

$I_{R_2}$ ________

$I_{R_3}$ ________

$I_{R_4}$ ________

$E_{R_2}$ ________

$E_{R_3}$ ________

$E_{R_4}$ ________

$I_{R_5}$ ________

$I_{R_6}$ ________

$E_{R_5}$ ________

$E_{R_6}$ ________

$I_{R_7}$ ________

$E_{R_7}$ ________

$I_{R_8}$ ________

$E_{R_8}$ ________

$I_{R_9}$ ________

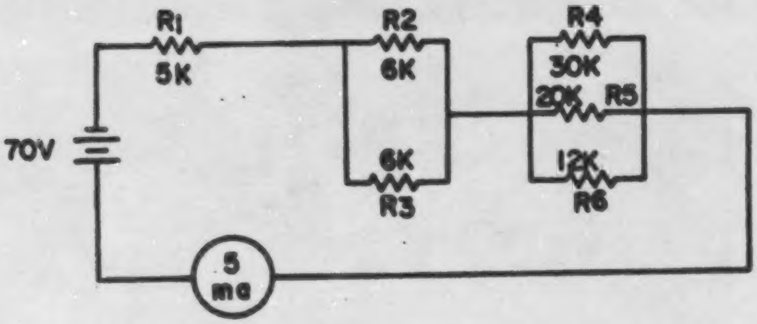
$I_{R_{10}}$ ________

$E_{R_9}$ ________

$E_{R_{10}}$ ________

## Module Self-Check

4.



Solve for:

$P_{R_1}$ ______

$P_{R_2}$ ______

$P_{R_3}$ ______

$P_{R_4}$ ______

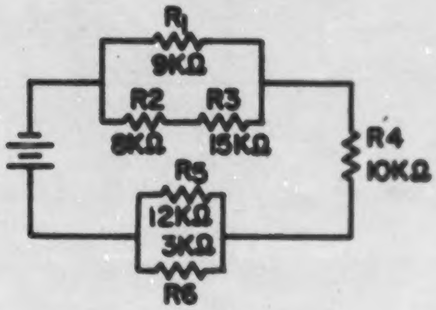
$P_{R_5}$ ______

$P_{R_6}$ ______

$P_T$ ______

ANSWERS TO MODULE SELF-CHECK

1.



The above drawing is one of the many schematic representations for a series parallel circuit.

2. $R_T = 23.8K\Omega$

3.

$R_T = 13K\Omega$

$I_T = 8ma$

$I_{R_1} = 8ma$

$E_{R_1} = 48V$

$I_{R_2} = 2.67ma$

$I_{R_3} = 2.67ma$

$I_{R_4} = 2.67ma$

$E_{R_2} = 26.7V$

$E_{R_3} = 16.V$

$E_{R_4} = 13.3V$

$I_{R_5} = 2.67ma$

$I_{R_6} = 2.67ma$

$E_{R_5} = 40V$

$E_{R_6} = 16V$

$I_{R_7} = 2.67ma$

$E_{R_7} = 48V$

$I_{R_8} = 2ma$

$E_{R_8} = 8V$

$I_{R_9} = .67ma$

$I_{R_{10}} = .67ma$

$E_{R_9} = 2.7V$

$E_{R_{10}} = 5.3V$

4.

$P_{R_1} = 125mw$

$P_{R_2} = 37.5mw$

$P_{R_3} = 37.5mw$

$P_{R_4} = 30mw$

$P_{R_5} = 45mw$

$P_{R_6} = 75mw$

$P_{RT} = 350mw$

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KEP-GP-9

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 9

## SERIES-PARALLEL RESISTIVE CIRCUITS

February 1976

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 8-3686

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
February 1976

# ELECTRONIC PRINCIPLES

## MODULE 9

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

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| Laboratory Exercise, 9-1 | 8 |
| Laboratory Exercise, 9-2 | 10 |
| Module Self Check | 11 |
| Answers | 13 |

## OVERVIEW

### SERIES-PARALLEL RESISTIVE CIRCUITS

1. SCOPE: The simple series or parallel circuit can not perform all of the functions that are required in todays electronic circuits. It is often necessary to combine series circuits with parallel circuits to form series-parallel circuits. The series-parallel circuit can appear to be very complex. However, by the application of the same rules used for series and parallel circuits, the complex circuits can be reduced to simple equivalent circuits. In this module, you will solve for resistance, current, and power. Practical exercises will give you practice in measuring unknown values of resistance, current, and voltage.

2. OJBECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a series-parallel circuit schematic diagram and formulas, solve for:

(1) total resistance.
(2) total current.
(3) total power.
(4) individual voltage drops.

b. Using a multimeter and a trainer with a loaded voltage divider, determine the polarity and measure the magnitude of a voltage with respect to the ground reference point within ± 10 percent accuracy.

c. Using a multimeter and a trainer with a three-component series-parallel resistive circuit, measure within ± 10 percent accuracy, the total resistance and individual voltage drops.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

## LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

---

Supersedes KEP-GP-9, 1 September 1975.

READING MATERIALS:

Digest
Adjunct Guide with Student Text

LABORATORY EXERCISE:

Resistive Circuits 9-1
Voltage Divider 9-2

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

---

## ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers against the answers at the back of this guidance package.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to Student Text Volume I and read paragraphs 5-116 thru 5-121. Return to this page and answer the following questions.

1. A definition of a series-parallel circuit is a group of:

______ a. Resistors connected in series with other resistors.

______ b. Series resistors connected in series with other resistors.

______ c. Parallel resistors connected in series with other resistors.

______ d. Resistors connected in parallel with other resistors.

2. When redrawing series-parallel circuits:

______ a. Parallel combinations of resistors cannot be represented by a single resistance.

______ b. Series combinations of resistors cannot be represented by a single resistance.

______ c. Always redraw them to only one parallel combination.

______ d. You are simplifying the circuit.

3. Why can't the branch currents be established using the full applied voltage?

______ a. A portion of the voltage is dropped across the series resistors.

______ b. The branch currents are unequal.

______ c. The voltage drops across the parallel resistors are unequal.

4. When total resistance increases in a series-parallel circuit and the voltage is held constant, the current:

______ a. increases.

______ b. decreases.

______ c. doubles.

______ d. remains the same.

5. If a parallel combination consists of two 50-ohm resistors and the voltage drop across them is 20 volts, the total power dissipated by this combination is:

______ a. 9 watts.

______ b. 16 watts.

______ c. 20 watts.

______ d. 50 watts.

6. If a parallel combination consists of two unequal value resistors:

______ a. They will dissipate equal amounts of power.

______ b. The largest resistor will dissipate the largest amount of power.

______ c. The smallest resistor will dissipate the largest amount of power.

______ d. The total power dissipated by the combination will be the difference of the two.

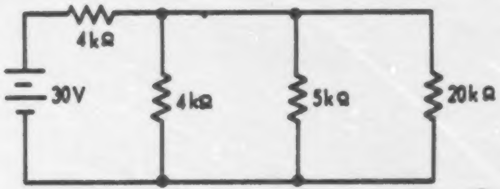
7. The total resistance in the figure below is

______ a. 2 k ohms.

______ b. 6 k ohms.

______ c. 8 k ohms.

______ d. 33 k ohms.



REP4-871

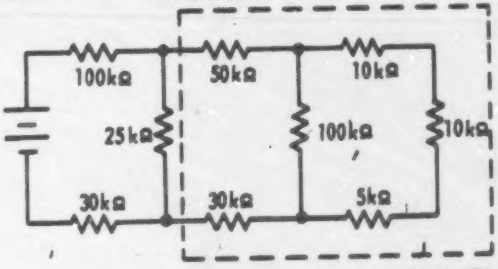
8. All of the resistors within the dotted line could be replaced by a resistor of:

______ a. 100 k ohms.

______ b. 25 k ohms.

______ c. 20 k ohms.

______ d. 150 k ohms.



REP4-872

9. In a circuit, a 50-ohm resistor is connected in series with two parallel resistors which are 60 and 40 ohms. What is the total resistance of the circuit?

______ a. 50 ohms.

______ b. 60 ohms.

______ c. 74 ohms.

______ d. 84 ohms.

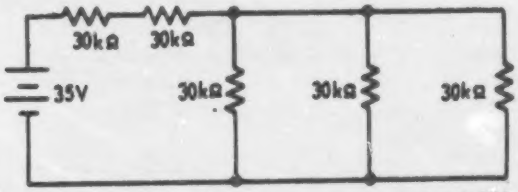
10. The total current is:

______ a. .25 mA.

______ b. .5 mA.

______ c. 1.5 mA.

______ d. 2 mA.



REP4-873

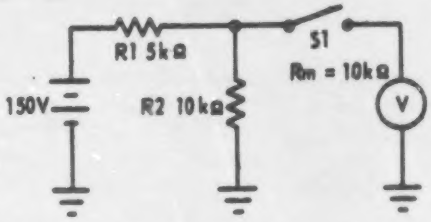
11. What is the voltage drop across R1 when S1 is closed?

______ a. 7.5 volts

______ b. 15 volts

______ c. 50 volts

______ d. 75 volts



REP4-875

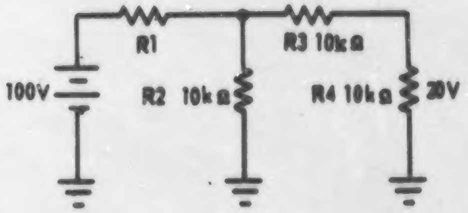
12. The value of R1 is:

______ a. 60 k ohms.

______ b. 20 k ohms.

______ c. 10 k ohms.

______ d. 6 k ohms.



REP4-876

13. The total power dissipated in the circuit in question 11 with S1 closed is:

______ a. 225 mW.

______ b. 2.25 W.

______ c. 22.5 W.

______ d. 225 W.

14. The total power dissipated in the circuit in question 12 is:

______ a. .3 W

______ b. .6 W.

______ c. .8 W.

______ d. .12 W.

CONFIRM YOUR ANSWERS

---

B. Turn to Student Text Volume I and read paragraphs 6-1 thru 6-11. Return to this page and answer the following questions.

1. The ground symbol used in a voltage divider denotes a:

______ a. Voltage source.

______ b. Current source.

______ c. Reference point.

______ d. Conducting chassis.

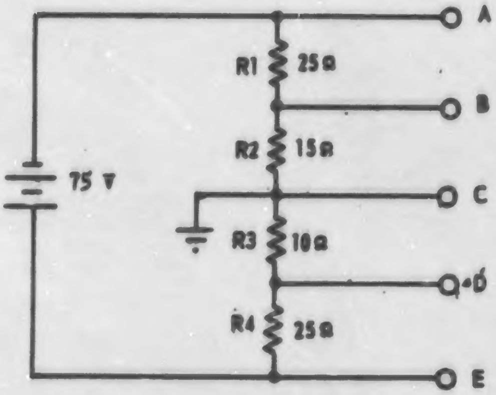
2. What is the voltage from point D to ground?

______ a. +10 V.

______ b. +15 V.

______ c. +30 V.

______ d. -35 V.



REP4-877

3. Using the circuit in question 2, moving the ground from point "C" to point "D" will cause the voltage at point "B" to change from -15 volts to

______ a. +10 volts.

______ b. +15 volts

______ c. -10 volts.

______ d. -25 volts.

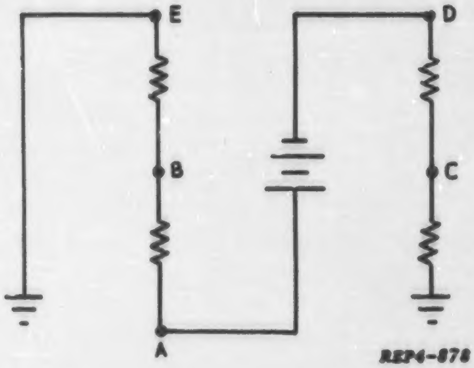
4. Which statement is true?

_____ a. Point D is positive in respect to B.

_____ b. Point C is positive in respect to D.

_____ c. Point A and ground are electrically the same.

_____ d. Points B and D are electrically the same.



REP4-878

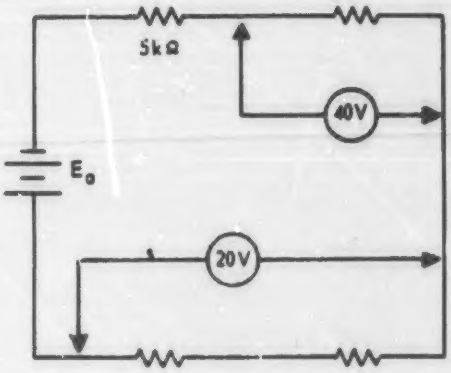
5. If I is 2 mA, $E_a$ is:

_____ a. 20 V.

_____ b. 70 V.

_____ c. 40 V.

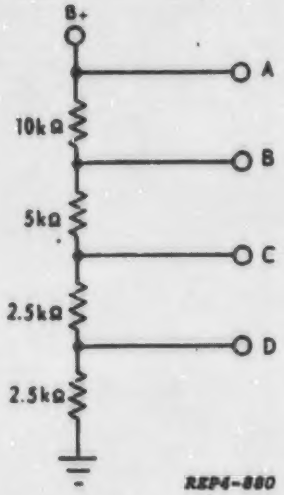
_____ d. 60 V.



6. If the voltage from "D" to "C" is -25 volts, what is the voltage at point B with respect to ground?

_____ a. 200 volts. _____ c. 75 volts.

_____ b. 100 volts. _____ d. 50 volts.

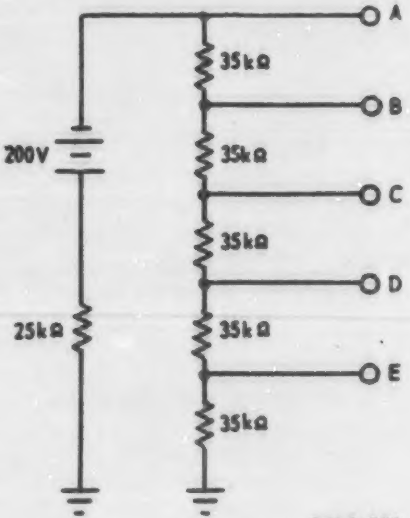


REP4-880

7. What is the voltage at "E" in respect to "C?"

_____ a. +120 V. _____ c. +70 V.

_____ b. -120 V. _____ d. -70 V.



REP4-881

CONFIRM YOUR ANSWERS

C. Turn to Student Text Volume I and read paragraphs 6-12 thru 6-26. Return to this page and answer the following questions.

1. A rheostat is a variable resistor which may be used to vary:

____ a. Voltage.

____ b. Current.

2. A rheostat has ________ active terminals.

____ a. Two.

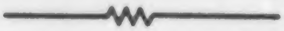
____ b. Three.

____ c. One.

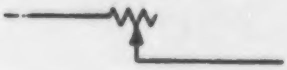
____ d. Four.

3. Which figure identifies a potentiometer being used as a rheostat?

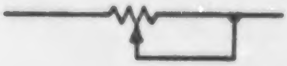
____ a.



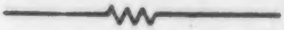
____ b.



____ c.



____ d.



REP4-684

4. The volume control on your radio is an example of:

____ a. A tapered rheostat.

____ b. A linear potentiometer.

____ c. A linear rheostat.

____ d. A tapered potentiometer.

5. The potentiometer has ______ active terminals.

____ a. Three.

____ b. Two.

____ c. Four.

____ d. One.

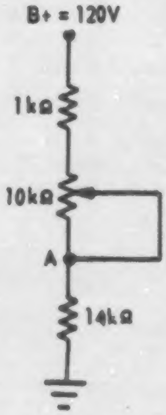
6. What is the minimum voltage obtainable at point A with respect to ground?

a. 112 volts.

b. 120 volts.

c. 67.2 volts.

d. 52.8 volts.



REP4-88.

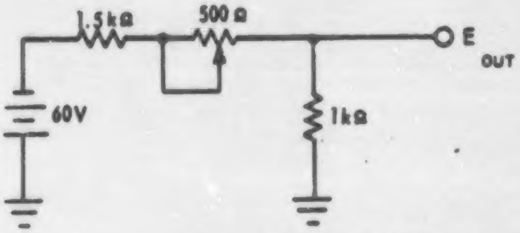
7. What are the minimum and maximum voltage at $E_{out}$?

____ a. 24 to 30 V.

____ b. 20 to 24 V.

____ c. -24 to -30 V.

____ d. -20 to -24 V.



REP4-883

CONFIRM YOUR ANSWERS

D. Turn to Student Text Volume I and read paragraphs 6-27 thru 6-42. Return to this page and answer the following questions.

1. What is meant by a loaded voltage divider?

_____ a. A tapped resistor is used in series to form a divider.

_____ b. A load device is placed in series with a tapped resistor.

_____ c. An electronic component or circuit which draws current from the source is placed across the divider.

_____ d. An electronic component or circuit which does not draw current is placed across the divider.

2. A loaded voltage divider has:

_____ a. Two or more paths for current flow.

_____ b. Only one path for current flow.

_____ c. One or more paths for current flow.

3. The term LOAD means:

_____ a. Voltage.

_____ b. Current.

_____ c. Resistance.

_____ d. Conductance.

4. When a load device is placed across a voltage divider the total resistance:

_____ a. Increases and load increases.

_____ b. Decreases and load decreases.

_____ c. Remains unchanged and load increases.

_____ d. Decreases and load increases.

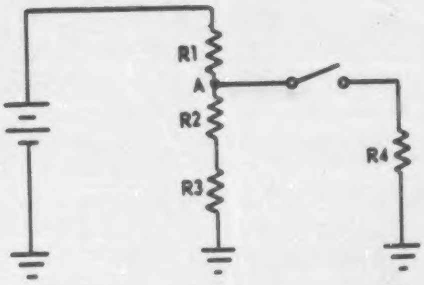
5. When the switch is closed, the:

_____ a. Voltage between point A and ground increases.

_____ b. Current through R1 decreases

_____ c. Current through R2 and R3 increases.

_____ d. Voltage between point A and ground decreases.



REP4-885

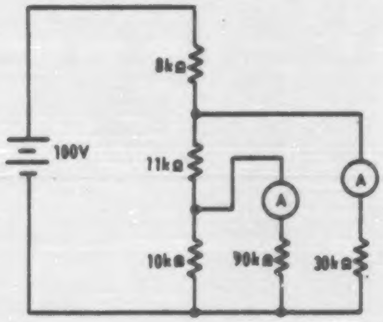
6. The total resistance is:

_____ a. 19 k ohms.

_____ b. 9 k ohms.

_____ c. 20 k ohms.

_____ d. 28 k ohms.



REP4-886

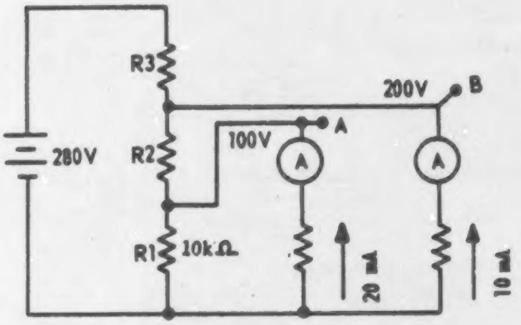
7. **What is the ohmic value of R3?**

_____ a. **2 k ohms**

_____ b. **2.67 k ohms**

_____ c. **5 k ohms**

_____ d. **20 k ohms**



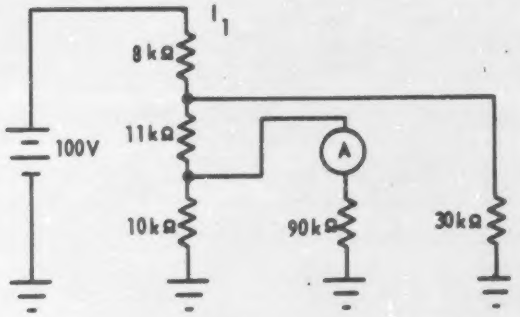
8. **In the figure $I_1$ equals:**

_____ a. **.3 mA.**

_____ b. **2.7 mA.**

_____ c. **3 mA.**

_____ d. **5 mA.**

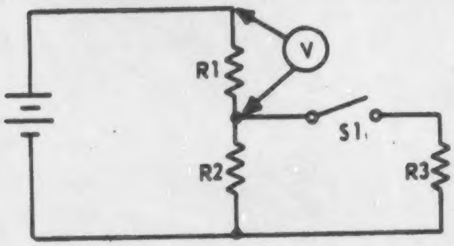


9. **When the switch is closed, the voltmeter reading will:**

_____ a. **Increase.**

_____ b. **Decrease.**

_____ c. **Remain the same.**



REP4-889

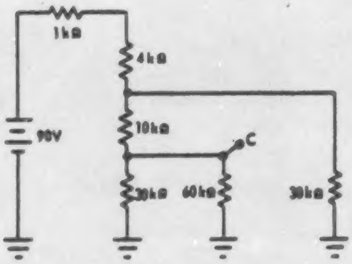
10. **The voltage at point C with respect to ground is:**

_____ a. **75 V.**

_____ b. **45 V.**

_____ c. **56 V.**

_____ d. **10 V.**



REP4-890

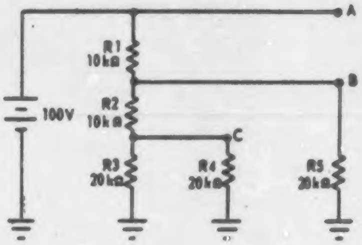
11. **What is the voltage at point B with respect to ground?**

_____ a. **25 volts.**

_____ b. **50 volts.**

_____ c. **75 volts.**

_____ d. **100 volts.**



REP4-891

12. To obtain both positive and negative voltage from a voltage-divider network, we can place ground at:

_____ a. Both ends of the network.

_____ b. Some point along the network.

_____ c. The positive end of the network.

_____ d. The negative end of the network.

13. $P_t$ in question 11 is:

_____ a. .5 W.

_____ b. 5 W.

_____ c. 10 W.

_____ d. 15 W.

CONFIRM YOUR ANSWERS

---

E. Turn to Laboratory Exercise 9-1. This exercise will help you gain experience with components and circuits.

---

## LABORATORY EXERCISE 9-1

## RESISTIVE CIRCUITS

**OBJECTIVES:**

1. Using a multimeter and a trainer with a three-component series-parallel resistive circuit, measure, within ±10 percent accuracy, the total resistance and individual voltage drops.

**EQUIPMENT:**

1. DC Resistor Trainer, 5631
2. AN/PSM-6
3. DC Power Supply, 4649

**REFERENCES:**

Student Text, Volume I, paragraphs 4-3 thru 4-22, 5-6, 5-70 thru 5-78, and 5-115 thru 5-121.

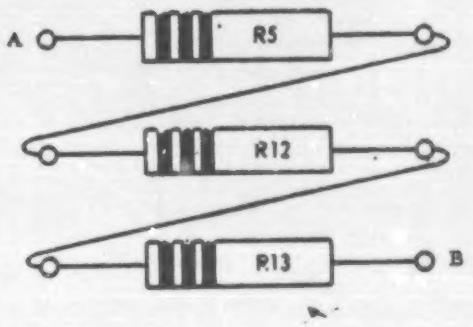
CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

**PROCEDURES:**

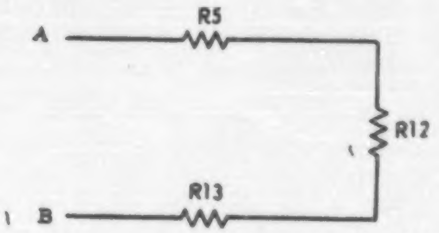
A. Series Circuit - Resistance Measurement

1. Using hook-up wires, connect R5, R12, and R13 in series.

2. Check your circuit. It should look like the drawing below.



This is the schematic diagram of this circuit.



REP4-493

3. Use the ohmmeter (PSM-6) and measure the total resistance of the circuit. Record the results.

_____________________________

4. Disconnect all hook-up wires.

CONFIRM YOUR ANSWER

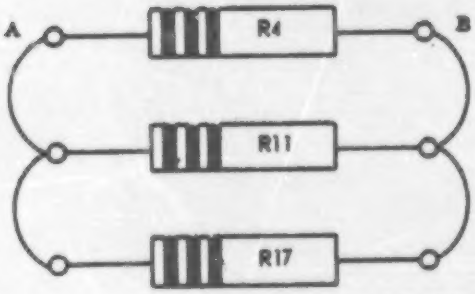
_____________________________

**B. Parallel Circuit - Resistance Measurement**

1. Using hook-up wires, connect R4, R11, and R17 in parallel.

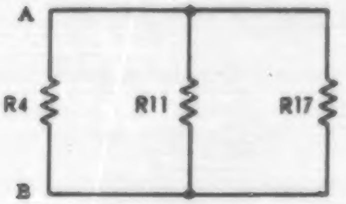
To construct this circuit, it will be necessary to have more than one wire on some of the binding posts.

2. Check your circuit. The completed circuit should look like this drawing.



REP4-895

This is the schematic diagram of this circuit.



REP4-897

3. Use the ohmmeter and measure the total resistance of this circuit. Record the results.

4. Disconnect all hook-up wires.

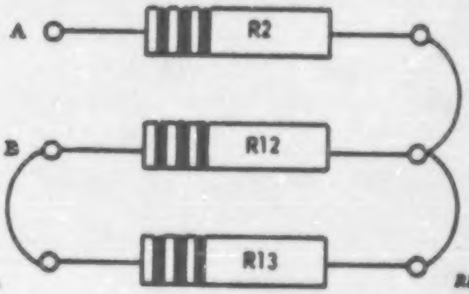
CONFIRM YOUR ANSWER

**C. Series-Parallel Circuit - Resistance Measurement.**

1. Using hook-up wires, connect R12 and R13 in parallel.

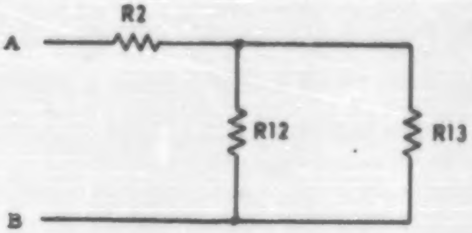
2. Connect R2 in series with the parallel combination.

3. Check your circuit. The completed circuit should look like this drawing.



REP4-894

This is the schematic of this circuit.



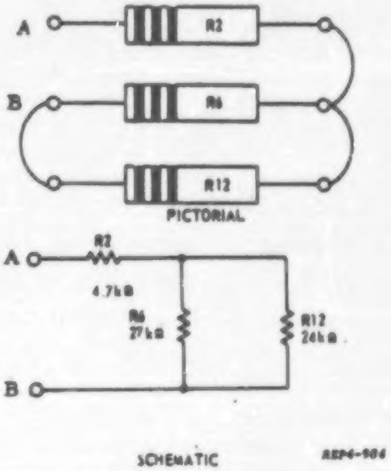
4. Use the ohmmeter and measure the total resistance of this circuit. Record the results.

5. Disconnect all hook-up wires.

CONFIRM YOUR ANSWER

D. Voltage Measurements

1. Connect R2, R6, and R12 in a series-parallel circuit as shown.



2. Connect the positive terminal of the point A and the negative terminal to point B.

3. Call your instructor to check your circuit.

4. Plug in and turn on the power supply.

5. Adjust the power supply for a 40 volt reading on the power supply meter.

6. Set the PSM-6 function switch to DCV/20 k/V and the range switch to 50 V.

7. Measure and record the individual voltage drops:

a. $E_{R2}$ ________ V DC.

b. $E_{R6}$ ________ V DC.

c. $E_{R12}$ ________ V DC.

CONFIRM YOUR ANSWERS

---

## LABORATORY EXERCISE 9-2

## LOADED VOLTAGE DIVIDER

### OBJECTIVE

Using a Multimeter and a trainer with a loaded voltage divider, determine the polarity and measure the magnitude of a voltage and respect to the ground reference point within ± 10 percent accuracy.

### EQUIPMENT:

1. DC Resistor Trainer, 5531
2. DC Power Supply, 4649.
3. PSM-6

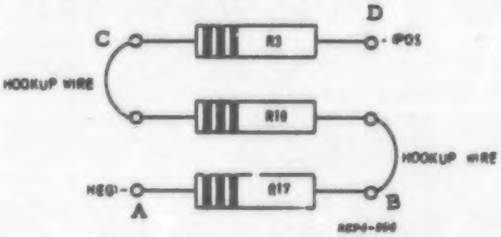
### REFERENCES:

Student Text, Volume I, paragraphs 6-1 thru 6-11. Review paragraphs 4-24 thru 4-30 if necessary.

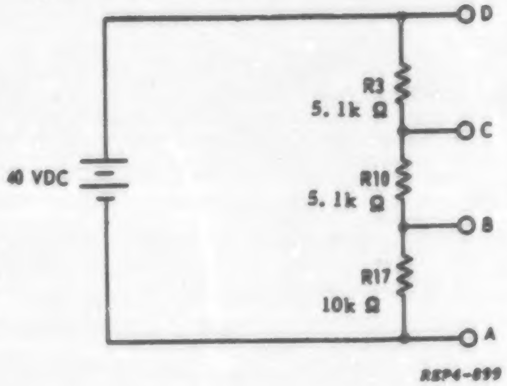
> CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

### PROCEDURES:

1. Connect R3, R10 and R17 in series as shown in the pictorial and connect the power supply to the points "A" and "D" as indicated. Observe polarity.



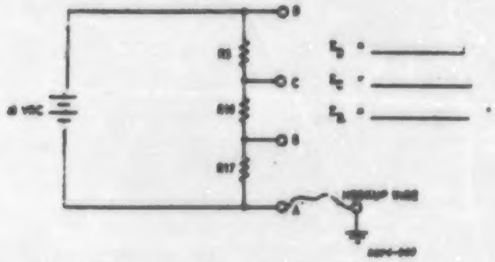
This is the schematic.



2. Connect a hook-up wire from a ground binding post in the trainer to point "A" of the circuit.

3. Turn on the power supply and adjust for a reading of 40 volts on the power supply meter. WARNING: TURN THE POWER SUPPLY OFF BEFORE MAKING ANY WIRING CHANGES. TURN THE SUPPLY ON AFTER MAKING THE CHANGES.

4. Using the PSM-6, measure the individual voltage drops in reference to ground. Record the voltage and polarity in the spaces provided.



$E_D$ = ______

$E_C$ = ______

$E_B$ = ______

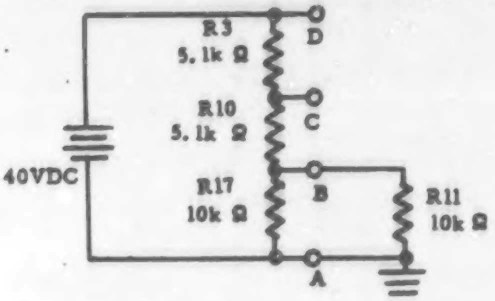
**CONFIRM YOUR ANSWERS**

---

5. Leave the hook-up from point "A" to ground.

6. Connect a resistor, R11, from a ground binding post and point "B" using hookup wire.

7. Using the multimeter, measure the individual voltages in reference to ground. Record the voltage and polarity in the space provided.



$E_D$ = ______ $E_C$ = ______

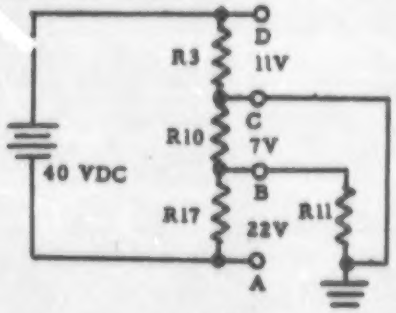
$E_B$ = ______ $E_A$ = ______

**CONFIRM YOUR ANSWERS**

---

8. Move the hookup wire from "A" to point "C." Leave R11 connected from ground to point "B."

9. Using the Multimeter, measure the individual voltages in reference to ground. Record the voltage and polarity in the space provided.



$E_D$ = ______ $E_C$ = ______

$E_B$ = ______ $E_A$ = ______

10. a. Why was the voltage at point "B" in step 7 less than the voltage at point "B" in step 4?

b. Why was the voltage at points "A" and "B" in step 9 negative?

c. Total resistance for the circuit in step 9 is (more)(less) than the circuit in step 7.

**CONFIRM YOUR ANSWERS.**

---

## MODULE SELF-CHECK

## SERIES-PARALLEL RESISTIVE CIRCUITS

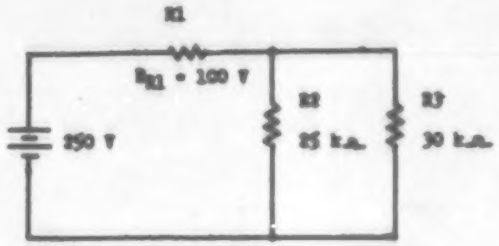
1. In the circuit below

a. total resistance is ______

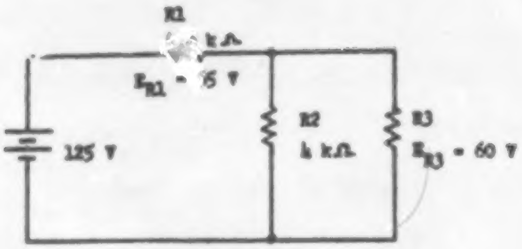
b. total current is ______

c. total power is ______

Remember E = IR and P = IE.



2. In the circuit shown



a. total resistance is ____________

b. total current is ____________

c. total power is ____________

CONFIRM YOUR ANSWERS

Remember E = IR and P = IE.

## ANSWERS TO A - ADJUNCT GUIDE

1. c
2. d
3. a
4. b
5. b
6. c
7. b
8. a
9. c
10. b
11. d
12. c
13. b
14. b

If you missed ANY questions, review the material before you continue.

## ANSWERS TO B:

1. c
2. a
3. d
4. b
5. b
6. b
7. c

If you missed ANY questions, review the material before you continue.

## ANSWERS TO C:

1. b
2. a
3. c
4. d
5. a
6. c
7. d

If you missed ANY questions, review the material before you continue.

## ANSWERS TO D:

1. c
2. a
3. b
4. d
5. d
6. c
7. a
8. d
9. a
10. b
11. b
12. b
13. a

If you missed ANY questions, review the material before you continue.

## ANSWERS TO LAB EXERCISE 9-1

A 3. Total resistance = 97 k ohm ± 10%

If you missed this question, ask your instructor for assistance.

B 3. Total resistance 1 3.33 k ohm ±10%

If you missed the question, ask your instructor for assistance.

C 4. Total resistance = 20.7 k ohm ±10%

If you missed the question, ask your instructor for assistance.

D 7a. 10 V DC.

7b. 30 V DC.

7c. 30 V DC.

If you missed ANY questions, ask your instructor for assistance.

## ANSWERS TO LAB EXERCISE 9-2

### ANSWERS TO PROCEDURE #4:

$E_D = +40V$

$E_C = +30V$

$E_B = +20 V$

$E_A = 0 V$

If you missed ANY questions, ask your instructor for assistance.

### ANSWERS TO PROCEDURE #7:

$E_D = +40 V$

$E_C = +26 V$

$E_B = +13 V$

$E_A = 0 V$

If you missed ANY questions, ask your instructor for assistance.

### ANSWERS TO PROCEDURE #9:

$E_D = +11 V$

$E_C = 0$ V

$E_B = -7$ V

$E_A = -29$ V

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO 10

a. The loading effect of R11 caused total resistance to decrease. Total current increased causing the voltage drop across R3 and R10 to increase. This leaves less voltage to be dropped across R17 and R11.

b. The ground reference point was moved to point "C." Current flow through R10 and R17 is from the negative terminal of the battery toward ground. Current flow toward ground causes a negative voltage drop.

c. Less

**ANSWERS TO MODULE SELF-CHECK:**

1. a. 22.7 k ohm

   b. 11 mA

   c. 2.75 W

2. a. 5 k ohm

   b. 25 mA

   c. 3.125 W

**HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.**

160

PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-10

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 10

## TROUBLESHOOTING DC RESISTIVE CIRCUITS

October 1975

AIR TRAINING COMMAND

7-5

Designed For ATC Course Use

ATC Keesler 6-1695

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-10
October 1975

# TROUBLESHOOTING DC RESISTIVE CIRCUITS

## MODULE 10

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

## CONTENTS

| TITLE | PAGE |
|---|---|
| Overview | 1 |
| List of Resources | 1 |
| Adjunct Guide | 1 |
| Laboratory Exercise, 10-1 | 8 |
| Laboratory Exercise, 10-2 | 10 |
| Laboratory Exercise, 10-3 | 13 |
| Laboratory Exercise, 10-4 | 15 |
| Module Self-Check | 16 |

---

## OVERVIEW

1. SCOPE: This module discusses the procedure for locating causes of circuit malfunctions. It also provides the necessary practical training on series, parallel, and series-parallel circuits using schematic diagrams, formulas, and a multimeter.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objective:

a. Using a multimeter, formulas, schematic diagram, and a trainer having an open or shorted component in a series-parallel resistive circuit, locate the faulty component.

## LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

LABORATORY EXERCISE:

Troubleshooting DC Resistive Circuits 10-1
Troubleshooting DC Resistive Circuits 10-2
Troubleshooting DC Resistive Circuits 10-3
Troubleshooting DC Resistive Circuits 10-4

AUDIO-VISUALS:

Television Lesson 30-101N Series Resistive Circuits T/S
Television Lesson 30-101T Series Parallel Circuits T/S

---

At this point, if you feel that through previous experience or training you are familiar with this subject, you may take the Module Self-Check. If not, select one of the resources and begin study.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

---

Supersedes KEP-GP-10, 15 July 1975. Previous editions are obsolete.

## ADJUNCT GUIDE

**INSTRUCTIONS:**

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers in the back of this guidance package.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to Student Text Volume I and read paragraphs 7-1 thru 7-30. Return to this page and answer the following questions.

1. A circuit in which no current flows is referred to as:

______ a. A short circuit.

______ b. A long circuit.

______ c. An open circuit.

______ d. A closed circuit.

2. When too much current flows in a circuit, it contains:

______ a. A short.

______ b. Too much resistance.

______ c. An open.

______ d. Discontinuity.

3. Which one of the following is NOT an example of an open?

______ a. Blown fuse.

______ b. Bare wires touching.

______ c. Burned out resistor.

______ d. Burned out lamp.

4. When you connect a voltmeter across a good resistor in an open circuit, the reading will be:

______ a. Infinite.

______ b. A portion of the applied voltage.

______ c. Zero.

______ d. The battery voltage.

5. When you connect an ohmmeter across an open component, the reading will be:

______ a. A large or small resistance.

______ b. Continuity.

______ c. Some reading.

______ d. Infinite resistance.

6. When the current exceeds the rated values for the components in circuit, what device is designed to open the circuit intentionally?

______ a. Switch.

______ b. Fuse.

______ c. Resistor.

______ d. Lamp.

7. In a circuit containing a shorted resistor, current will continue to flow if the power dissipated by each resistor is:

______ a. Lower than its power rating.

______ b. Less than total dissipated power.

______ c. Higher than its power rating.

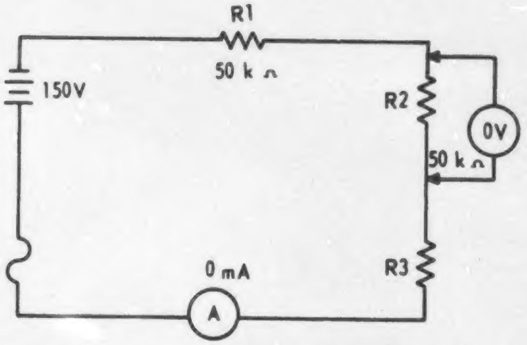
______ d. More than total dissipated power.

8. If a circuit is fused at 2 amps, what is the maximum voltage that could be applied if circuit resistance is 100 ohms?

______ a. 50V ______ c. 200V

______ b. 100 V ______ d. 20V

9. What is wrong with this circuit?



REP4-1166

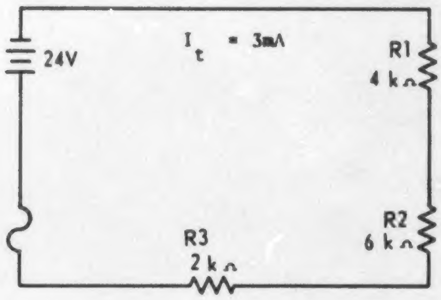
_____ a. R1 open.

_____ b. R1 shorted.

_____ c. R2 shorted.

_____ d. R3 shorted.

10. The trouble in this circuit is:
NOTE: Current is 2 milliamperes when the circuit is operating normally.



REP4-1167

_____ a. Fuse open.

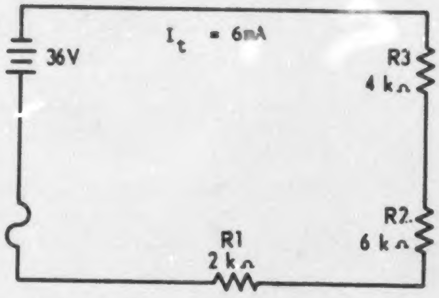
_____ b. R1 shorted.

_____ c. R2 shorted.

_____ d. R3 shorted.

11. What is the trouble in this circuit?

Note: Current is 3 milliamperes when the circuit is operating normally.



REP4-1168

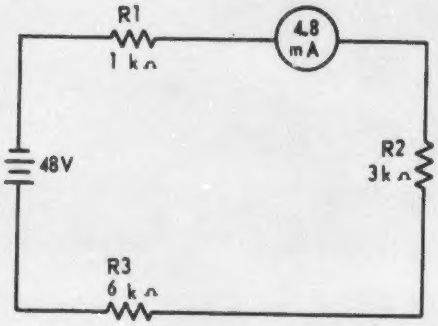
_____ a. Fuse open.

_____ b. R1 shorted.

_____ c. R2 shorted.

_____ d. R3 shorted.

12. What is wrong with this circuit?



REP4-1170

_____ a. R3 open.

_____ b. R2 shorted.

_____ c. R2 open.

_____ d. Nothing -- circuit is good.

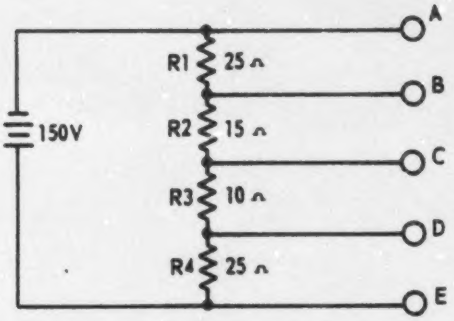
13. If R1 in this circuit were shorted,

_____ a. $I_t$ would be 3 mA.

_____ b. The voltage from C to E would be 105 volts.

_____ c. $R_t$ would be 25 ohms.

_____ d. $I_t$ would be 2A.



REP4-1171

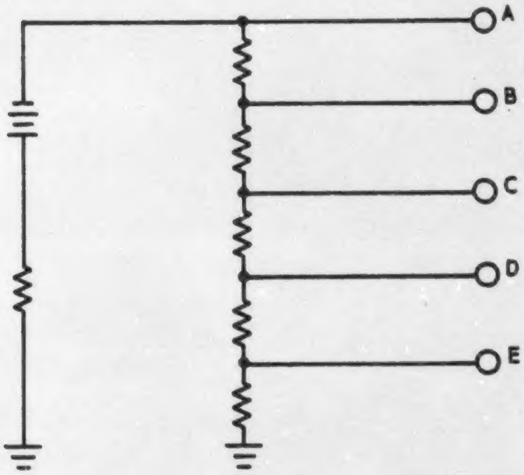
14. If point "B" shorts to ground, what happens to the voltage from C to E?

_____ a. Decreases.

_____ b. Increases.

_____ c. Remains the same.

_____ d. Changes polarity.



REP4-1172

CONFIRM YOUR ANSWERS

---

B. Turn to Laboratory Exercise 10-1. This exercise will introduce series resistive circuit troubleshooting procedures.

---

C. Turn to Student Text Volume I and read paragraphs 7-31 thru 7-42. Return to this page and answer the following questions.

1. When troubleshooting a parallel circuit with an ammeter, the open branch resistor can be located by a reading of:

_____ a. Zero current.

_____ b. Infinite resistance.

_____ c. Zero resistance.

_____ d. Total current.

2. In a parallel circuit that contains three branch resistors, if one resistor suddenly burns completely open, what will happen to the circuit?

_____ a. The fuse will blow.

_____ b. The total resistance decreases.

_____ c. The total resistance increases.

_____ d. The current through the other resistors increases.

3. When a short occurs in a parallel circuit, the:

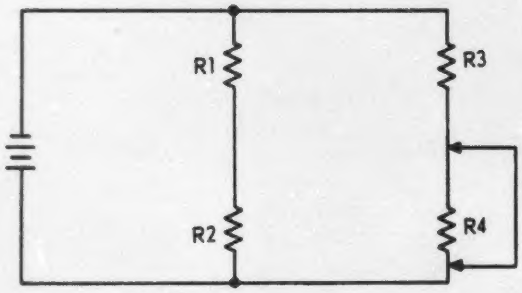
_____ a. total resistance increases.

_____ b. total current decreases.

_____ c. total current increases.

_____ d. individual resistances increase.

4. How would a short across R4 affect the power dissipated by R2?



REP4-1173

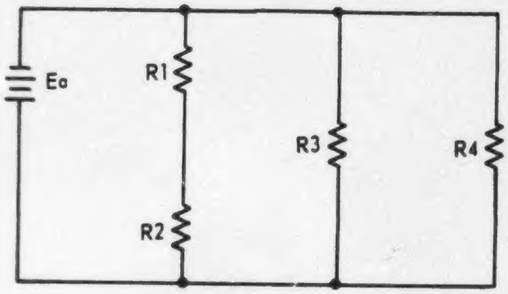
____ a. Increases.

____ b. Decreases.

____ c. Remains the same.

____ d. Cannot be determined.

5. If R4 should "short" the voltage across R1 will:



REP4-1175

____ a. Be applied voltage.

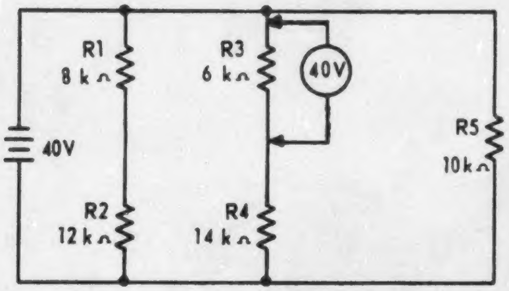
____ b. Increase.

____ c. Be zero.

____ d. Not change.

6. The voltmeter gives an indication of what probable trouble?

NOTE: Normal indication of the voltmeter is 12 volts.



REP4-1176

____ a. R3 shorted.

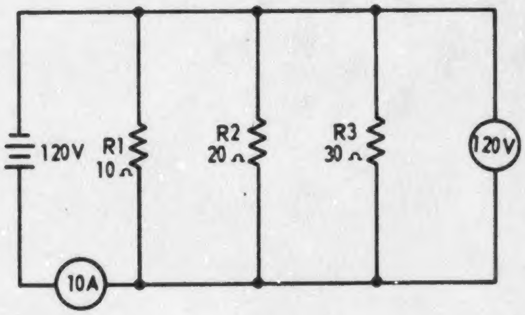
____ b. R5 shorted.

____ c. R4 open.

____ d. R3 open.

7. What is the trouble in the circuit below:

NOTE: Current is 22 amperes when the circuit is operating normally.



REP4-1177

____ a. R1 is shorted.

____ b. R3 is shorted.

____ c. R1 is open.

____ d. R2 is open.

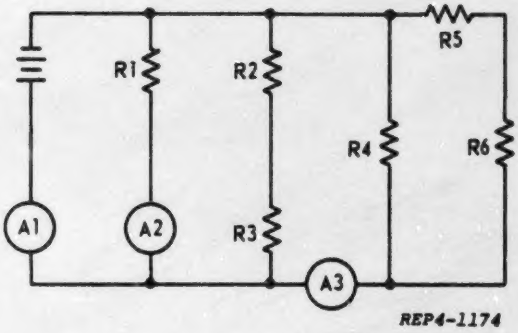
8. Which of the following conditions would be true if R5 opens?

$A_1$ increases
______a. $A_2$ no change
$A_3$ increases

$A_1$ decreases
______b. $A_2$ decreases
$A_3$ decreases

$A_1$ increases
______c. $A_2$ decreases
$A_3$ increases

$A_1$ decreases
______d. $A_2$ no change
$A_3$ decreases



CONFIRM YOUR ANSWERS

---

D. Turn to Laboratory Exercise 10-2. This exercise will introduce parallel resistance circuit troubleshooting procedures.

---

E. Turn to Student Text Volume I and read paragraphs 7-43 thru 7-62. Return to this page and answer the following questions.

1. If an open occurs in the series portion of a series-parallel circuit, the current will:

______ a. Increase.
______ b. Remain the same
______ c. Cease to flow.
______ d. Blow the fuse.

2. When a shorted component is contained in the series portion of a series-parallel circuit, the total current will:

______ a. Stop.
______ b. Increase.
______ c. Decrease.
______ d. Remain the same.

3. When an open occurs in the parallel portion of a series-parallel circuit, the voltage drop across the series resistor will:

______ a. Increase.
______ b. Decrease.
______ c. Remain the same.
______ d. Equal the applied voltage

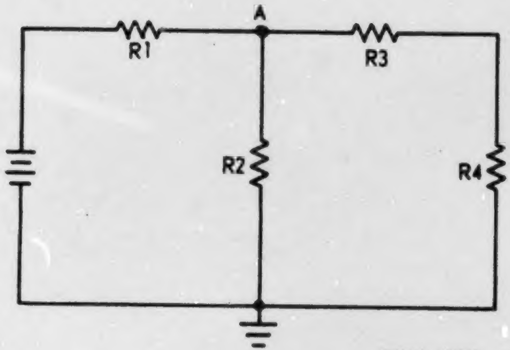
4. When a short occurs in the parallel portion of a series-parallel circuit, the total resistance of the circuit will:

______ a. Decrease.
______ b. Remain the same.
______ c. Increase.
______ d. Be zero.

5. If a voltmeter is connected across a good series resistor in a series-parallel circuit, the meter will read:

______ a. The applied voltage.
______ b. A portion of the applied voltage.
______ c. Zero.

6. If R3 were shorted, the voltage at point A with respect to ground will:



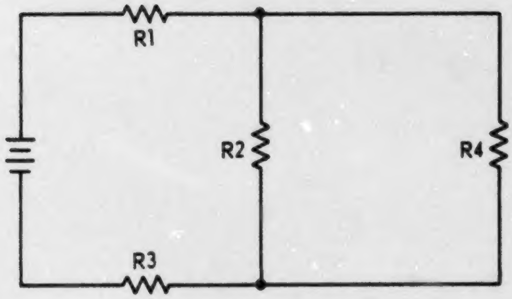
REP4-1178

______ a. Increase.

______ b. Decrease.

______ c. Remain the same.

7. If R2 opens, which of the following statements is true?



REP4-1179

______ a. $R_t$ decreases.

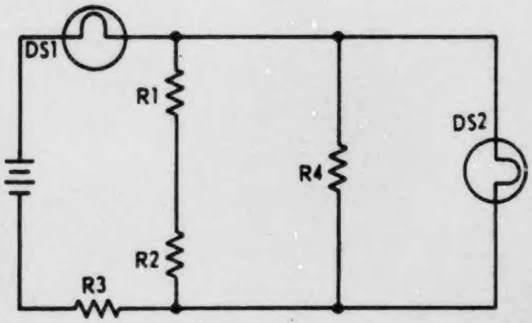
______ b. $E_{R1}$ increases.

______ c. $E_{R2}$ decreases.

______ d. $I_t$ decreases.

8. What could cause DS1 to become dimmer while DS2 becomes brighter?

NOTE: Remember more current causes a lamp to be brighter and less current to become dimmer.



REP4-1180

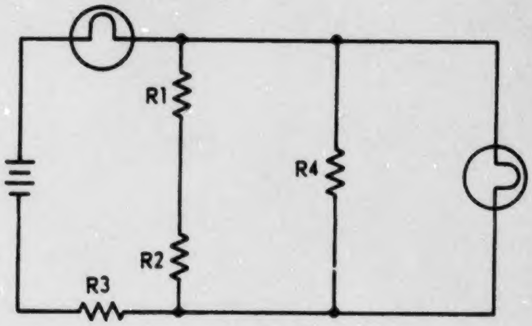
______ a. R1 short.

______ b. R2 open.

______ c. R3 open.

______ d. R4 short.

9. What would cause both bulbs to become brighter?



REP4-1181

______ a. R1 short.

______ b. R2 short.

______ c. R3 short.

______ d. R4 open.

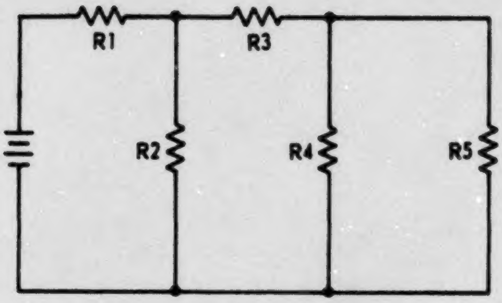
10. If R5 opens, the current through:

______ a. R1 increases.

______ b. R2 decreases.

______ c. R4 increases.

______ d. R4 remains the same.



REP4-1182

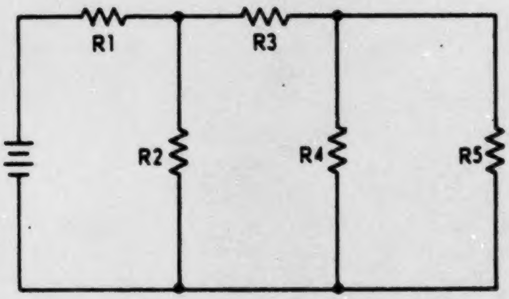
11. In the circuit below if R4 opens, the current through:

____ a. R1 increases.

____ b. R1 decreases.

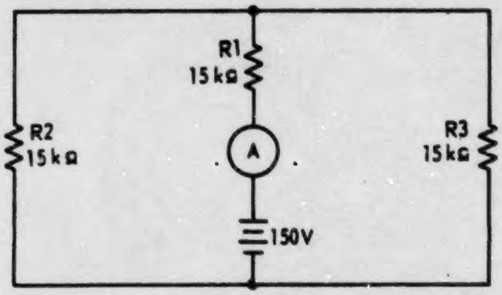
____ c. R2 decreases.

____ d. R2 remains the same.



REP4-1183

12. In the figure below, if R1 shorts, the ammeter will read:



REP4-1184

____ a. 20 micro amps.

____ b. 10 mA.

____ c. 20 mA.

____ d. 30 mA.

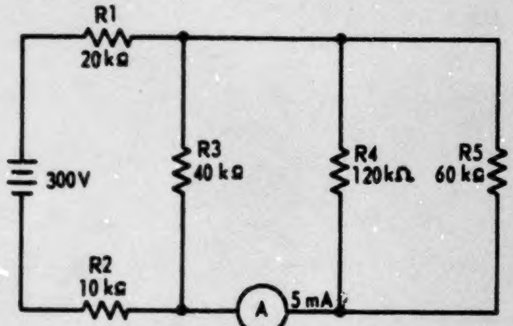
13. In the circuit below, the ammeter reads 5 mA. The trouble is:

____ a. R2 open.

____ b. R5 shorted.

____ c. R5 open.

____ d. R1 short.



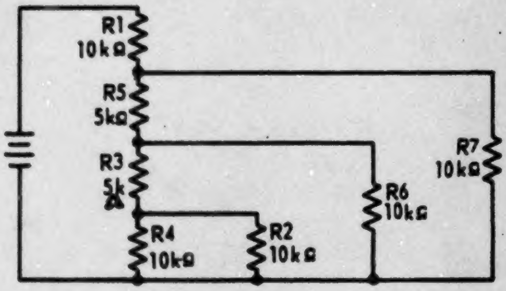
REP4-1185

14. Refer to the figure below. If R2 becomes open, the total power will:

____ a. Increase.

____ b. Decrease.

____ c. Remain the same.



REP4-1186

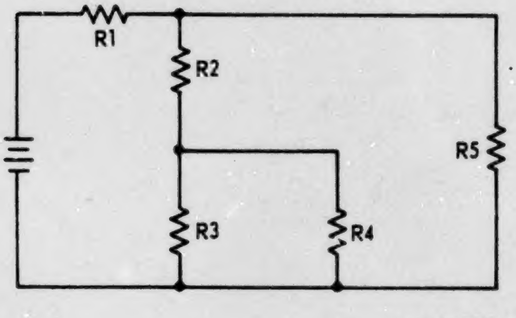
15. Which of the following will cause the voltage across R2 to decrease but not go to zero?

_____ a. R5 short.

_____ b. R4 open.

_____ c. R2 short.

_____ d. R1 open.



REP4-1187

CONFIRM YOUR ANSWERS

---

F. Turn to Laboratory Exercise 10-3. This exercise will introduce you to series-parallel circuit troubleshooting procedures.

---

G. Now do laboratory exercise 10-4. This exercise will prepare you for the Progress Check on troubleshooting series-parallel resistive circuits.

---

AFTER COMPLETING THE LABORATORY EXERCISES AND PROGRESS CHECK, YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## LABORATORY EXERCISE 10-1

OBJECTIVE:

Using a multimeter, formulas, schematic diagram, and a trainer having an open or shorted component in a series-parallel resistive circuit, locate the faulty component.

LEARNING STEP:

1. Determine what effect a short has on a series circuit.

2. Determine what effect an open has on a series circuit.

EQUIPMENT:

1. DC Resistor Trainer 5531
2. DC Power Supply 4649
3. Multimeter PSM-6

REFERENCES:

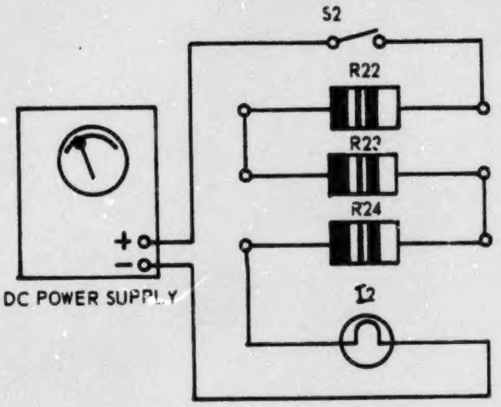
Student Text, Volume I, paragraphs 7-1 thru 7-30.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

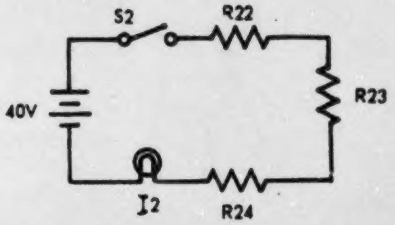
A. Circuit Analysis.

1. Connect switch 2 (in the opened position), lamp I-2, R22, R23 and R24 in a series circuit as shown in the pictorial diagram and adjust the power supply for 40 volts.



REP4-2611

The following is the schematic diagram of the circuit above.



REP4-2610

2. In learning to troubleshoot DC series resistive circuits, it is important to know what indications a circuit projects when everything is in proper working order.

a. Close switch S-2.

b. Measure and record:

$E_{R22}$ ____________ VDC

$E_{R23}$ ____________ VDC

$E_{R24}$ ____________ VDC

I2 (lamp) ____________ VDC

CONFIRM YOUR ANSWERS

---

3. You will now simulate a resistor shorted.

a. Place a hook-up wire across R24.

NOTE: Remember that current takes the path of least resistance and will now short around the resistor instead of traveling thru it. Also note the increased brightness of the lamp I2. This indicates an increase in current due to the reduction of the overall resistance by the simulated removal of R24 from the circuit.

b. Measure and record:

$E_{R22}$ ____________ VDC

$E_{R23}$ ____________ VDC

$E_{R24}$ ____________ VDC

I-2 ____________ VDC

---

SUMMARY: It can now be seen that a short produces an increase in current by reducing the overall resistance. Voltage will be redistributed across the remaining resistors in accordance with Kirchhoff's Voltage Law.

4. Now simulate a resistor burned open.

(Remember that an open means that continuity has been lost and current does not have a complete path).

a. Open switch S-2 to simulate a resistor that has burned open. LEAVE S-2 IN THE OPEN POSITION.

b. Measure and record:

(1) $E_{R22}$ ____________ VDC

(2) $E_{R23}$ ____________ VDC

(3) $E_{R24}$ ____________ VDC

(4) I-2 ____________ VDC

Place the voltmeter across the switch. (The simulated burned out resistor.)

$E_{sw}$ ____________ VDC

CONFIRM YOUR ANSWERS

---

SUMMARY: An open circuit is a circuit that has lost continuity and current flow will be zero. When checking with a voltmeter all the good resistors will indicate zero volts, but when the voltmeter is placed across the opened resistor it will read the applied voltage.

5. Thus far you have seen what effect a shorted resistor and an open resistor have on current, when checking the circuit with a voltmeter. Now use an ohmmeter to observe the indications that a shorted or open resistor will produce.

CAUTION: When using the ohmmeter POWER MUST BE REMOVED from the circuit.

a. Turn the power supply OFF.

b. Disconnect the power supply from the circuit by removing the circuit hookup wires connected to the red and black terminals on the power supply.

c. Again use switch S2 as a simulated resistor. In the open position the switch simulates a burned out resistor and in the closed position it simulates a shorted resistor. (Switch S2 should be in the open position). Place the ohmmeter across the switch.

NOTE: When checking an open circuit the ohmmeter should be on the highest range.

____________________ ohms

CONFIRM YOUR ANSWER

---

d. Close switch S2 (Simulating a shorted resistor). NOTE: When checking for a shorted component, the ohmmeter should be on the lowest range.

____________________ ohms.

CONFIRM YOUR ANSWER

---

SUMMARY: A voltmeter has definite indications when placed across an open or shorted component in a series circuit. When placed across an open component the voltmeter will indicate the applied voltage. When placed across a shorted component the voltmeter will indicate zero volts. The ohmmeter, like the voltmeter, also has definite indications when placed across an open or shorted component. When placed across an open component the ohmmeter will indicate infinite ohms and when placed across a shorted component it will indicate zero ohms.

Remove all hookup wires.

---

## LABORATORY EXERCISE 10-2

OBJECTIVE:

Using a multimeter, formulas, schematic diagram, and a trainer having an open or shorted component in a series-parallel resistive circuit, locate its faulty component.

LEARNING STEP:

1. Determine what effect a short has on a parallel circuit.

2. Determine what effect an open has on a parallel circuit.

EQUIPMENT:

1. DC Resistive Trainer 5531
2. DC Power Supply 4649
3. Multimeter PSM-6

REFERENCES:

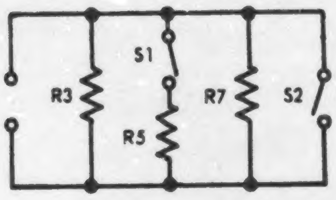
Student Text, Volume I, paragraphs 7-31 thru 7-42.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURE:

A. Circuit Analysis

1. It would be difficult to simulate a short in a parallel circuit with the power applied. The schematic diagram shows that

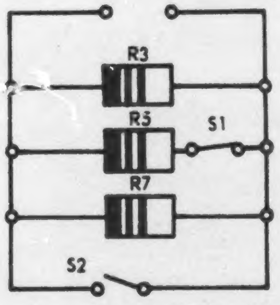


REP4-2606

with a shorted component (S2 is a simulated resistor) in a one resistor branch, you would place the short directly across the battery causing the fuse to blow and or circuit breaker to trip because of the short ... (Remember current always takes the path of least resistance.) Consequently for this portion of the laboratory exercise use the ohmmeter to perform the tests.

DO NOT CONNECT THE POWER SUPPLY TO THE CIRCUIT.

2. Connect R3, R5, S1, R7, S2 in a parallel circuit as shown in the pictorial diagram.



REP4-2609

(NOTE: Position S1 closed and S2 open).

3. Place the leads of the ohmmeter in the connectors at the top of the trainer. (Rx 1000 range) measure and record the total resistance.

$R_t$ ____________________

CONFIRM YOUR ANSWER

______________________________

4. Now simulate a shorted resistor.

a. Close switch S-2

b. Measure and record.

$R_t$ ____________________

c. Open switch S-2

CONFIRM YOUR ANSWER

______________________________

SUMMARY: You can now see that a short, in a one resistor branch, would cause the fuse to blow if a power supply were connected. Due to the short, $R_t$ would be zero ohms and $I_t$ would be infinite.

5. The circuit will remain connected for the next experiment. Now simulate a resistor burned open.

a. Open switch S1. (This simulates R5 burned open and continuity in this branch lost).

b. Measure and record

$R_t$ ____________________

c. What would have happened to total current if the power had been applied to the circuit?

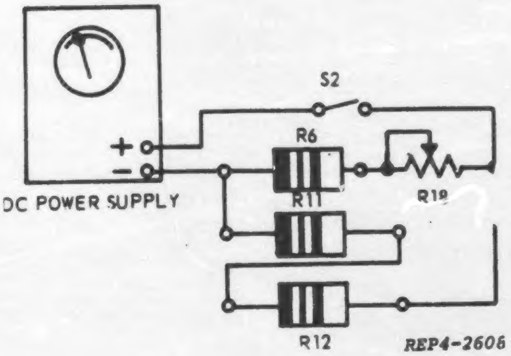
CONFIRM YOUR ANSWERS

______________________________

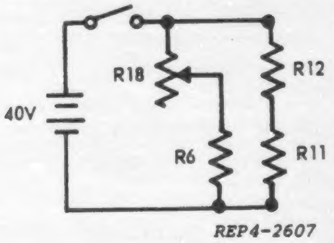
SUMMARY: When a branch in a parallel circuit is lost through an open, total resistance increases and total current decreases.

6. When two or more resistors comprise a branch in a parallel circuit, although similar in many ways, circuit conditions have some differences from the one resistor branch.

a. Connect switch S2 (In the open position), R6, R11, R12, and R18 (White connector) in a parallel circuit as shown in the pictorial diagram and adjust the power supply for 40 volts. (Set R18 fully CW or the maximum resistive position).



The following is the schematic diagram of the circuit above.



b. Close switch S2

c. Measure and Record

$E_{R18}$ ______________ VDC

$E_{R6}$ ______________ VDC

$E_{R11}$ ______________ VDC

$E_{R12}$ ______________ VDC

e. Open switch S2.

CONFIRM YOUR ANSWERS

---

SUMMARY: You can see from your answers that R18 and R6 comprise one circuit with the Power Supply ($E_A = E_{R18} + E_{R6}$) and R11 and R12 comprise the other ($E_A = E_{R11} + E_{R12}$). This also shows that voltage is common or the same across each branch of the parallel circuit but divides according to the size of the resistors in the individual branches.

7. We will now simulate a shorted resistor. Turn R18 to the extreme CCW position.

(This action reduces the resistance of R18 to zero ohms and simulates a shorted resistor).

a. Close switch S2

b. Measure and record

$E_{R18}$ ______________ VDC

$E_{R6}$ ______________ VDC

$E_{R11}$ ______________ VDC

$E_{R12}$ ______________ VDC

c. Open switch S2

CONFIRM YOUR ANSWERS

---

SUMMARY: It can be seen that the applied voltage in the first branch is now across R6 due to R18 being short. More importantly, we find that the conditions occurring in Branch I had no effect on Branch II. What was affected was total circuit resistance (it decreased) and as a result total circuit current increased.

8. An open circuit in a two resistor branch would have similar indications as the one resistor branch discussed in paragraph 5 above. When a resistor opens in a parallel branch that branch has lost continuity and no current will flow. The remaining branches will continue to function with no change due

to the common voltage. Again what will be affected will be total circuit resistance (increase) and total circuit current (decrease).

TURN OF THE POWER SUPPLY AND REMOVE ALL HOOKUP WIRES.

---

## LABORATORY EXERCISE 10-3

**OBJECTIVE:**

Using a multimeter, formulas, schematic diagram, and a trainer having an open or shorted component in a series-parallel resistive circuit, locate the faulty component.

**LEARNING STEPS:**

1. Determine the effects of a short on a series-parallel circuit.

2. Determine the effect of an open on a series-parallel circuit.

**EQUIPMENT:**

1. DC Resistor Trainer 5531
2. DC Power Supply 4649
3. Multimeter PSM-6

**REFERENCES:**

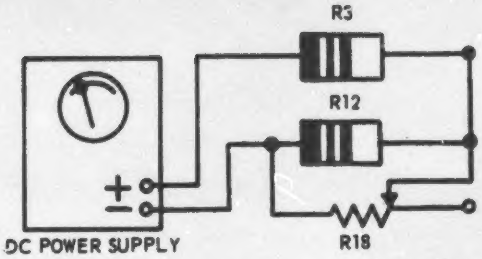
Student Text, Volume I, paragraphs 7-43 thru 7-62.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY AT ALL TIMES. REMOVE WATCHES AND RINGS.

**PROCEDURE:**

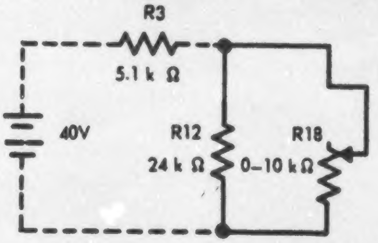
A. Circuit Analysis.

1. Connect R3, R12 and R18 in a series-parallel circuit as shown in the pictorial diagram and adjust the power supply for 40 volts. (Adjust R18 fully clockwise or to the 10K position).



REP4-2605

The following is the schematic diagram with the dotted line representing the series portion of the circuit, (it has total current flowing thru it) and the solid line representing the parallel portion. (Total current splits inversly proportional to the size of the resistors.)



REP4-2604

2. Measure the voltage drops to ascertain the conditions with the circuit in proper working order.

$E_{R3}$ ________________ VDC

$E_{R12}$ ________________ VDC

$E_{R18}$ ________________ VDC

CONFIRM YOUR ANSWERS

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3. We will now perform an experiment in the series portion of the circut by shorting and opening R3. First we will simulate R3 shorting.

a. Turn off the Power Supply.

b. Place a hookup wire across R3.

CAUTION: At this point it is important to insure that R18 (Variable Resistor) is set to its maximum resistor value. If it is set to the zero ohms position and R3 is shorted you have a direct short across the battery and the power supply circuit breaker will trip. Recall, current always takes the path of least resistance and by placing a wire across R3, current will now short around the resistor instead of traveling thru it.

c. Turn on the power supply

d. Measure and Record

E

$E_{R3}$ ____________ VDC

$E_{R12}$ ____________ VDC

$E_{R18}$ ____________ VDC

e. Turn off the power supply

f. Remove the simulated short across R3.

CONFIRM YOUR ANSWERS.

SUMMARY: A short across R3 (in this series portion) makes this circuit a parallel circuit. The applied voltage is across each branch with no voltage appearing across the short.

4. Now simulate resistor R3 burning open. (Remember that R3 is in the series path. An open at this point means that current no longer has a complete path and will stop)..

a. Remove the hookup wire from the left side binding post of R3. (This action "breaks" the circuit and simulates R3 burned open).

b. Turn on the power supply.

c. Measure and Record

$E_{R3}$ ____________ VDC

(Place voltmeter leads acorss the open by placing the red lead on the power supply's red post and the black lead on the right side binding post of R3).

$E_{R12}$ ____________ VDC

$E_{R18}$ ____________ VDC

d. Turn off the power supply

e. Replace the power supply hookup wire to R3.

CONFIRM YOUR ANSWER.

SUMMARY: When an open occurs in the series portion of the circuit you will read the applied voltage across the open while all other components would read zero volts. (Remember to have a voltage drop you have to have current and resistance).

5. So far in the series-parallel circuit you have seen the effects of opening and shorting a resistor in the series portion of the circuit, (R3). Now observe the effects of shorting and opening a resistor in the parallel portion of the circuit. First simulate a short.

a. Turn R18 fully counter clock-wise. (This action reduces R18 to zero ohms and simulates a shorted resistor). What has happened to total resistance? ____________

b. Turn on the power supply

c. Measure and Record

$E_{R3}$ ____________ VDC

$E_{R12}$ ____________

$E_{R18}$ ____________ VDC

d. Turn off the power Supply

e. Turn R18 fully clockwise (full resistance position).

CONFIRM YOUR ANSWERS.

SUMMARY: A short in the parallel branch of a series-parallel circuit will remove the resistance and no voltage will appear in that part of the circuit. The applied voltage will be redistributed across the series components in accordance with Kirchhoffs Voltage Law. The total resistance will be the sum of the series resistors.

6. Simulate R18 burned open by removing the hookup wire from the left binding post of R18. (This action causes loss of current through that branch).

a. What happens to total resistance?

______________________________

b. Turn on the ppwer supply.

c. Measure and record

$E_{R3}$ ______________ VDC

$E_{R12}$ ______________ VDC

$E_{R18}$ ______________ VDC

(NOTE: To measure $E_{R18}$, place the voltmeter across the open by placing the red lead on the right hand post of R3 and the black lead on the black post of the power supply).

d. Turn off the power supply.

e. Remove all hookup wires.

CONFIRM YOUR ANSWERS.

SUMMARY: When a branch of a series-parallel circuit opens, it's continuity is lost. The voltage will be redistributed in accordance with Kirchhoffs Voltage Law. This will cause an increase in total resistance and a decrease in current.

## LABORATORY EXERCISE 10-4

### OBJECTIVE:

Using a multimeter, formulas, schematic diagram, and a trainer having an open or shorted component in a series-parallel resistive circuit, locate the faulty component.

### EQUIPMENT:

1. DC Resistor Trainer 5531
2. DC Power Supply 4649
3. Multimeter PSM-6

### REFERENCES:

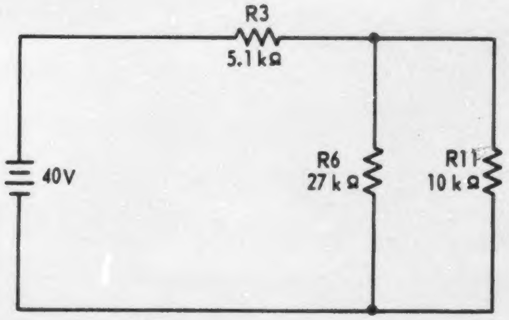
Student Text, Volume I, paragraphs 7-43 thru 7-62.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

### PROCEDURE:

A. Troubleshooting.

1. Using R3, R6, and R11, construct the circuit shown in the diagram and apply power.



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NOTE: Provisions are provided in this trainer for opening or shorting components.

2. Have your instructor check your circuit and prepare the trainer for troubleshooting.

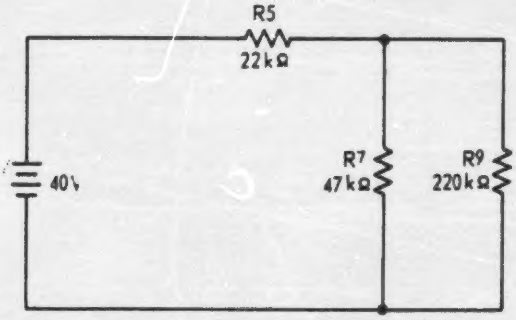
3. Use the PSM-6 to locate the faulty component and note whether the component is open or shorted.

R __________ is (opened) (shorted).

4. Have your instructor check your results.

5. Turn off power supply and disconnect all hook-up wires.

6. Using R5, R7, and R9, construct the circuit shown in the diagram and apply power.



REP4-1193

7. Have your instructor check your circuit and prepare the trainer for troubleshooting.

8. Use the PSM-6 to locate its faulty component and note whether the component is opened or shorted.

R ________ is (opened) (shorted).

9. Have your instructor check you results.

10. Turn off the power supply and disconnect all hook-up wires.

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

## MODULE SELF-CHECK

1. A circuit in which no current flows is referred to as

______ a. a short circuit.

______ b. a long circuit.

______ c. an open circuit.

______ d. a closed circuit.

2. When too much current flows in a circuit, it contains

______ a. a short.

______ b. too much resistance.

______ c. an open.

______ d. discontinuity.

3. When you connect a voltmeter across a good resistor in an open series circuit, the reading will be

______ a. infinite.

______ b. a portion of the applied voltage.

______ c. zero.

______ d. the battery voltage.

4. When you connect an ohmmeter across an open component, the reading will be:

______ a. a large or small resistance.

______ b. continuity.

______ c. some reading.

______ d. infinite resistance.

5. Symptom: $I_t$ = 1.6 mA, the faulty component is:

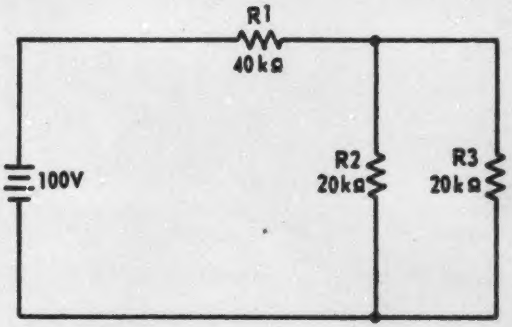
______ a. R1 open.

______ b. R1 shorted.

______ c. R2 open.

______ d. R3 shorted.

Remember, E = IR



REP4-1188

6. Symptom: $E_{R1}$ = 0V and $E_{R2}$ = 300V, the faulty component is:

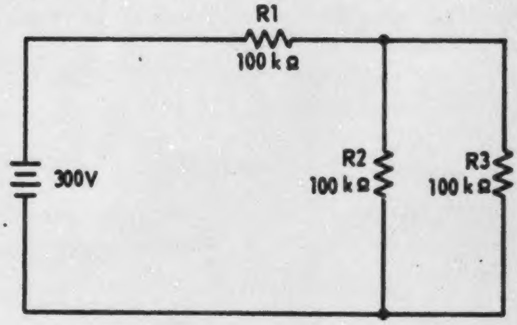
______ a. R1 open.

______ b. R1 shorted.

______ c. R2 shorted.

______ d. R3 open

Remember, E = IR



REP4-1189

CONFIRM YOUR ANSWERS

______________________________

## ANSWERS TO A - ADJUNCT GUIDE

1. c
2. a
3. b
4. c
5. d
6. b
7. a
8. c
9. a
10. b
11. c
12. d
13. b
14. a

If you missed ANY questions, review the material before you continue.

## ANSWERS TO C - ADJUNCT GUIDE

1. a
2. c
3. c
4. c
5. c
6. d
7. c
8. d

If you missed ANY questions, review the material before you continue.

## ANSWERS TO E - ADJUNCT GUIDE

1. c
2. b
3. b
4. a
5. b
6. b
7. d
8. b
9. c
10. c
11. b
12. c
13. d
14. b
15. b

If you missed ANY questions, review the material before you continue.

## ANSWERS TO LAB EXERCISE 10-1

2b. $E_{R22}$ 5-7 volts
$E_{R23}$ 5-7 volts
$E_{R24}$ 11-13 volts
I-2 13-15 volts

If you missed any questions recheck your work or call the instructor for assistance.

3b. $E_{R22}$ 8-9 volts
$E_{R23}$ 8-9 volts
$E_{R24}$ 0 volts
I-2 20-22 volts

4b. $E_{R22}$ 0 volts
$E_{R23}$ 0 volts
$E_{R24}$ 0 volts
I-2 0 volts
$E_{SW}$ 40-43 volts

5c. Infinite ohms

5d. Zero ohms

## ANSWERS TO LAB EXERCISE 10-2

3. 4-4.5 k ohms
4b. 0 ohms
5b. 5K ohms
5c. decreased
6c. $E_{R18}$ 9 - 11 volts
$E_{R6}$ 28 - 30 volts
$E_{R11}$ 10 - 12 volts
$E_{R12}$ 27-29 volts

7b. $E_{R18}$ 0 volts
$E_{R6}$ 40 volts
$E_{R11}$ 10-12 volts
$E_{R12}$ 27 - 29 volts

## ANSWERS TO LAB EXERCISE 10-3

2. $E_{R3}$ 16-19 volts
$E_{R12}$ 21-23 volts
$E_{R18}$ 21-23 volts

3d. $E_{R3}$ 0 volts
$E_{R12}$ 40 volts
$E_{R18}$ 40 volts

4c. $E_{R3}$ 40 volts
$E_{R12}$ 0 volts
$E_{R18}$ 0 volts

5a. $R_t = R3$

5c. $E_{R3}$ 40 volts
$E_{R12}$ 0 volts
$E_{R18}$ 0 volts

6a. $R_t$ has increased (R3 & R12 now in series)

6c. $E_{R3}$ 6 - 8 volts
$E_{R12}$ 32 - 34 volts
$E_{R18}$ 32 - 34 volts

## ANSWERS TO MODULE SELF-CHECK

1. c
2. a
3. c
4. d
5. c
6. b

HAVE YOU ANSWERED ALL OF THE QUESTIONS? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.